POWER QUALITY IMPROVEMENT USING PASSIVE SHUNT FILTER, TCR AND TSC COMBINATION

A Thesis Submitted in Partial Fulfillment
of the Requirements for the Award of the Degree of

Master of Technology
in
Electrical Engineering
(Control & Automation)

By

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Roll no-210EE3294

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Department of Electrical Engineering
National Institute of Technology,
Rourkela -769008, India.
MAY 2012

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DEPARTMENT OF ELECTRICAL ENGINEERING
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ROURKELA, ODISHA-769008

CERTIFICATE

This is to certify that the thesis entitled, **“POWER QUALITY IMPROVEMENT USING PASSIVE SHUNT FILTER, TCR AND TSC COMBINATION”** submitted by **MISS MANJULATA BADI** bearing roll no. **210EE3294** in partial fulfillment of the requirements for the award of **Master of Technology** Degree in **Electrical Engineering** with specialization in **“CONTROL & AUTOMATION”** during 2010-2012 session at the National Institute of Technology, Rourkela is an authentic work carried out by her under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Date:

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I am thankful for the constant moral support of my friends and family without which this work have been impossible

Manjulata Badi

ABSTRACT

Power system harmonics are a menace to electric power systems with disastrous consequences. The line current harmonics cause increase in losses, instability, and also voltage distortion. With the proliferation of the power electronics converters and increased use of magnetic, power lines have become highly polluted. Both passive and active filters have been used near harmonic producing loads or at the point of common coupling to block current harmonics. Shunt filters still dominate the harmonic compensation at medium/high voltage level, whereas active filters have been proclaimed for low/medium voltage ratings. With diverse applications involving reactive power together with harmonic compensation, passive filters are found suitable [41]. Passive filtering has been preferred for harmonic compensation in distribution systems due to low cost, simplicity, reliability, and control less operation [42].

The uncontrolled ac-dc converter suffers from operating problems of poor power factor, injection of harmonics into the ac mains, variations in dc link voltage of input ac supply, equipment overheating due to harmonic current absorption, voltage distortion due to the voltage drop caused by harmonic currents flowing through system impedances, interference on telephone and communication line etc.

The circuit topologies such as passive filters, ac-dc converter, based improved power quality ac-dc converters are designed, modeled and implemented. The main emphasis of this investigation has been on a compactness of configurations, simplicity in control, reduction in rating of components, thus finally leading to saving in overall cost. Based on thesis considerations, a wide range of configurations of power quality mitigators are developed, which is expected to provide

detailed exposure to design engineers to choose a particular configuration for a specific application under the given constraints of economy and desired performance. For bidirectional power flow applications, the current source converter is designed and simulated with R-L load. The necessary modeling and simulations are carried out in MATLAB environment using SIMULINK and power system block set toolboxes. The behavior of different configurations of passive tuned filters on power quality is studied. One of the way out to resolve the issue of reactive power would be using filters and TCR, TSC with combination in the power system. Installing a filter for nonlinear loads connected in power system would help in reducing the harmonic effect. The filters are widely used for reduction of harmonics. With the increase of nonlinear loads in the power system, more and more filters are required. The combinations of passive filters with TCR and TSC are also designed and analyzed to improve the power quality at ac mains. This scheme has resulted in improved power quality with overall reduced rating of passive components used in front end ac-dc converters with R-L load.

CONTENTS

LIST OF FIGURES

NOMENCLATURE

d-q	Synchronously rotating reference frame direct and quadrature axes
i_d	d-axis current
i_q	q-axis current
ɵ	Angle of stationary reference frame
R_{PF}	Filter resistance
L_{PF}	Filter inductance
R	Load resistance
L	Load inductance
i_a, i_b, i_c	Are line current in a, b, c phase
P	Active Power
Q	Reactive Power
α	Firing Angle
B_{TCR}	Susceptance at thyristor control reactor
ω	Synchronously rotating frequency
V_T	Voltage at thyristor
V_C	Voltage at Thyristor switch capacitor
V_{dq}	Voltage in d-q reference frame

ABBREVIATIONS

PCC	Point of common coupling
PLL	Phase locked loop
PSF	Passive shunt filter
TCR	Thyristor controlled Reactor
TSC	Thyristor switched Capacitor
THD	Total harmonic Distortion
P-I	Proportional and integral controller
SRF	Synchronous reference Frame
FACTS	Flexible ac transmission
LPF	Low pass filter

INTRODUCTION

1.1 BACKGROUND

Harmonics and reactive power regulation and guidelines are upcoming issues and increasingly being adopted in distributed power system and industries. Vital use of power electronic appliances has made power management smart, flexible and efficient. But side by side they are leading to power pollution due to injection of current and voltage harmonics. Harmonic pollution creates problems in the integrated power systems. The researchers and engineers have started giving effort to apply harmonic regulations through guidelines of IEEE 519-1992. Very soon customers have to pay and avail the facility for high performance, high efficiency, energy saving, reliable, and compact power electronics technology. It is expected that the continuous efforts by power electronics researchers and engineers will make it possible to absorb the increased cost for solving the harmonic pollution.

The thyristor controlled reactors of various network configurations are widely used in industries and utility systems for harmonic mitigation and dynamic power factor correction. These thyristor controlled reactor operate as a variable reactance in both the inductive and capacitive domains. By means these two parameters two types of problems are normally encountered. The first problem is the reactive power (Var) that leads to poor power factor and the harmonics appears due to presence of power converter devices and nonlinear loads for example, electrics machines, fluctuating industrial loads, such as electric arc furnaces, rolling mills, power converters etc. These types of heavy industrial loads are normally concentrated in one plant and served from one network terminal, and therefore, can be handled best by a local compensator connected to the same terminal.

The main emphasis of the investigation has been on compactness of configurations, simplicity in control, reduction in rating of components, thus finally leading to saving in overall cost. Based on these considerations, a wide range of configurations of power quality mitigators are developed for providing a detailed exposure to the design engineer in selection of a particular configuration for a specific application under the given constraints of economy and the desired performance. Fig 1.1 shows a classical shunt passive filter is connected the power system through common coupling point (PCC). Because of using non-linear load, the load current is highly non-linear in nature. The compensating current which is the output of the shunt passive filter is injected in PCC, by this process the harmonic cancellation take place and current between the sources is sinusoidal in nature. The passive filter is popular in cancellation of harmonic current in power system. To control this process, there are two ways i.e.

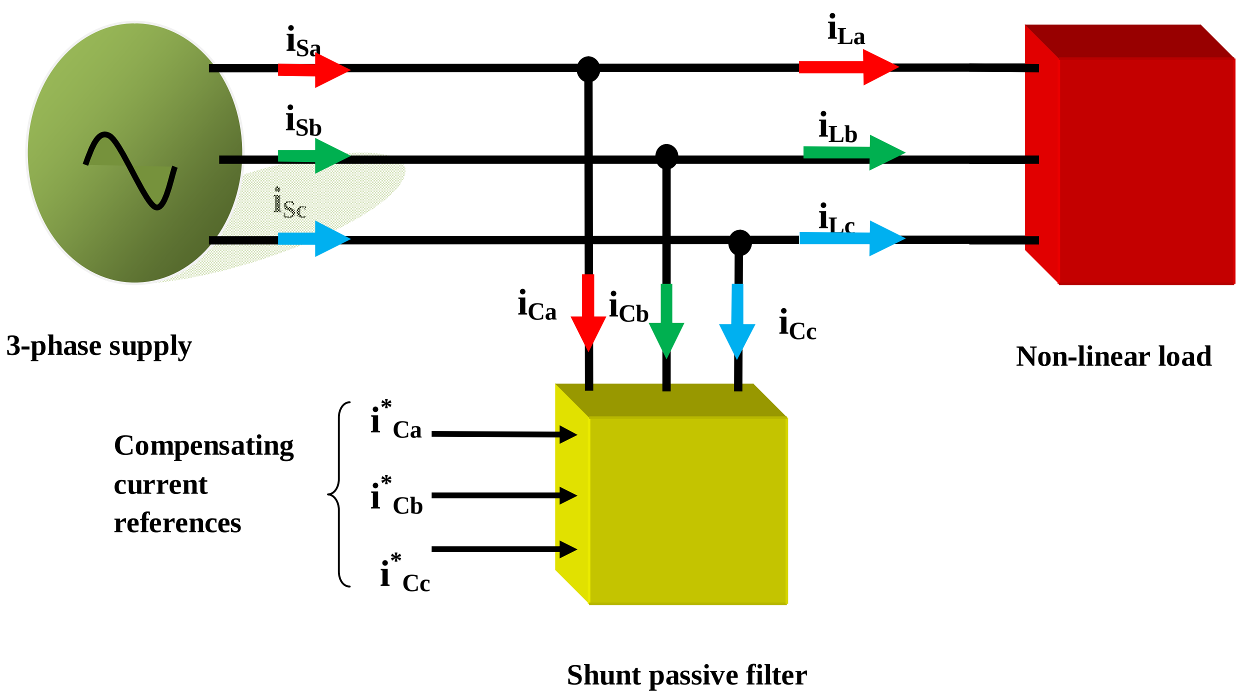

Fig1.1 The Classical Shunt Passive Filter

(i)Harmonic extraction technique

(ii)Current modulator

1.1.2 Harmonic Extraction

The harmonic extraction is the process in which, reference current is generated by using the distorted waveform. Many theories have been developed such as p-q theory (instantaneous reactive power theory), d-q theory, P-I controller, adaptive controller etc. Out of these theories more than 60% research works have been consider p-q theory and d-q theory due to their accuracy, robustness and easy calculation.

1.1.3 Current Modulator

Current modulator mainly provides the gate pulse to the ac-dc converter. There may be many techniques used for giving the gate signals to PWM VSI or CSI such as sinusoidal PWM, triangular PWM etc.

The above described two control techniques (harmonic extraction technique and current modulator technique) are main research foci of many researchers in recent years. It may be noted that either harmonics extraction technique or the current modulator can be used individually or both at a time. Apart from these two techniques, most of the research works are directed also in dealing with multi-level rectifier control problems.

1.2 LITERATURE REVIEW

1.2.1 INTRODUCTION

An overwhelming breadth of the literature, covering different techniques for power quality improvement at ac mains of ac-dc converter is available. The research work has been reported in the area of power quality improvement. The implementation of various international standards has been given further impetus to innovate new configurations of power quality converters to adhere to these standard limits. The motivation for developing new configurations has been focused mainly to reduce the rating of magnetic, to simplify the control circuitry, to improve the efficiency of the system and finally to bring down the cost the complete system. The exhaustive literature review is carried out on different techniques used for power quality of ac-dc converter. It also includes literature survey of control techniques normally used in reduction of reactive power.

1.2.2 SIGNIFICANT DEVELOPMENTS

The international standards [45, 47] have led to the significant developments in numerous harmonic mitigation techniques. The use of passive filters for three phase supply systems [48-49], use of thyristor controlled reactor and thyristor switched capacitor with combination has been the significant developments.

For three-phase supply systems, use of passive filters has been reported three decades back. Since then, different design techniques for passive filter have been reported for achieving their optimum performance using reduced rating of the passive filters.

The current injection techniques have been used in existing six-pulse ac-dc converter to achieve 12,18,24,30 and higher pulse configurations. These configurations result in simple circuitry; simple control and they are rugged, reliable and economical.

1.2.3 LITERATURE SURVEY

During last decade, substantial research has been carried out in innovating different new configurations for harmonic mitigation in ac-dc converter with R-L load. There have been a number of developments in control techniques used in power system. The literature survey carried out in this research work has been divided into three main categories with further classification.

K. V. Kumar [1], have been presented the performance comparison of Shunt Active Power Filter (SAPF) and Hybrid Active Power Filter (HAPF) with three different non linear loads. Two different PI controllers based on average load active power and synchronous reference frame theory are employed in this simulation study. MATLAB/ SIMULINK is used for the simulation of SAPF and HAPF.

B. Singh, K. Al-Haddad [2], he presents a comprehensive review of active filter (AF) configurations, control strategies, selection of components, other related economic and technical considerations, and their selection for specific applications.

J. W. Dixon [3], he has been studied analytically and tested using computer simulations and experiments. In the experiments, it has been verified that the filter keeps the line current almost sinusoidal and in phase with the line voltage supply. It also responds very fast under sudden changes in the load conditions, reaching its steady state in about two cycles of the fundamental.

L. A. Morán[4], describes different power quality problems in distribution systems and their solutions with power electronics based equipment. Shunt, hybrid and series active power filters are described showing their compensation characteristics and principles of operation. Different power circuits topologies and control scheme for each type of active power filter are analyzed. The compensation characteristics of each topology with the respective control scheme are proved by simulation and experimentally.

Mahesh Singh [5]**,** he identified the prominent concerns in the area and thereby to recommend measures that can enhance the quality of the power, keeping in mind their economic viability and technical repercussions. In this paper electromagnetic transient studies are presented for the following two custom power controllers: the distribution static compensator (D-STATCOM), and the dynamic voltage restorer (DVR). Comprehensive results are presented to assess the performance of each device as a potential custom power solution.

Charles. S [6], he proposed a three of the three-phase shunt active filtering algorithms in time-domain have been compared for a non-linear load. The non-linear load chosen here is a soft-start for a three-phase induction motor. The comparison of the simulation results show the effectiveness of both the algorithms although the time domain current detection modified algorithm is more complex in terms of its implementation aspects.

S. P. Litran [7], he combined system of shunt passive and series active filter for a four-wire three-phase system has been designed and simulated with MATLAB/SIMULINK. The system combined mitigates the source current harmonics and compensates also unbalance voltages reducing the problems of using only a shunt passive filter. Therefore, a new control method based in the power vector theory has been proposed.

Salvador P. Litran[8], he described three different control strategies have been applied to a series active filter. The first is based on that the filter voltage must be proportional to the harmonic of the source current. With the second strategy the filter voltage must be equal to voltage harmonics on the side load but in opposition. The third strategy is hybrid control where the filter voltage is obtained using both previous strategies.

L. Chen [9], he suggested that an assessment and comparison of hybrid active filters, including their topologies, ratings, and control algorithms. Simulations are presented, along with a comprehensive topology and performance comparison. In addition, a modified "p-q" theory is introduced for control strategies, which is more feasible for extracting harmonic components for distorted load voltages.

K. Karthik, St. Johns [10], he proposed a control scheme based on synchronous d-q-0 transformation for a hybrid series voltage compensator. The effectiveness of the new control scheme in compensating for voltage sags, distortion and voltage flickers is demonstrated using simulation results. Its dual role as a harmonic isolator is also described. A comparison between the proposed schemes against an existing control scheme is presented via simulation.

E. R. Ribeiro [11], have been presented a series active filter using a simple control technique. The series active filter is applied as a controlled voltage source contrary to its common usage as variable impedance. It reduces the terminal harmonic voltages, supplying linear or even nonlinear loads with a good quality voltage waveform. The operation principle, control strategy, and theoretical analysis of the active filter are presented.

Hideaki Fujita [12], he presents a combined system of a passive filter and a small-rated active filter, both connected in series with each other. The passive filter removes load produced harmonics just as a conventional one does. On the other hand, the active filter plays a role in improving the filtering characteristics of the passive filter.

Hideaki Fujita [13], have already proposed the combined system of a shunt passive filter and a small-rated series active filter. The purpose of the series active filter is to solve such a problem as series and parallel resonance which is inherent in a shunt passive filter used alone.

F. Zheng Peng [14], he a combined system of shunt passive and small rated series filters has already been proposed by the authors. The operating principle and steady compensation characteristics have been presented as well.

Karuppanan P. and K. K. Mahapatra[15], the shunt APLC system is implemented with three phase current controlled Voltage Source Inverter (VSI) and is connected at the point of common coupling for compensating the current harmonics by injecting equal but opposite filter currents. The compensation process is based on PLL synchronization with PI or PID or fuzzy logic controller.

Salem Rahmani [16], he compare the performance of the single-phase shunt active power filter (SPSAPF) and the single-phase shunt hybrid power filter (SPSHPF) that adopt both an indirect current control scheme with a uni-polar pulse width modulation (UPWM) strategy. The SPSHPF topology includes, in addition to the components of the SPSAPF, a power factor correction capacitor connected in series with a transformer.

T. Mahalekshmi[17], here the current harmonic can be compensated by using the Shunt Active Power Filter, Passive Power Filter and the combination. The system has the function of voltage stability, and harmonic suppression. The reference current can be calculated by 'dq' transformation. An improved generalized integrator control was proposed to improve the performance of APF.

R V D Rama Rao[18], he presents performance validation of Current Source Inverter (CSI)-based UPQC using Fuzzy Logic Controller (FLC) and Results are compared with conventional PID Controller and improvements are observed by FLC. The FLC-based compensation scheme eliminates voltage and current magnitude of harmonics with good dynamic response

Yash Pal Singh [19], Power supplies used for powering of magnets in INDUS-I and INDUS-II use different type of power converters including SMPS and thyristorised power converters.. In all the high power dc power supplies, wide variation in operating point leads to a considerable amount of reactive power generation and harmonic loading on ac mains.

N. Karpagam[24], he proposed a fuzzy logic based supplementary controller for Static VAR Compensator (SVC) is developed which is used for damping the rotor angle oscillations and to improve the transient stability of the power system. Generator speed and the electrical power are chosen as input signals for the Fuzzy Logic Controller (FLC).

S. A. Khaparde[25], he proposed work is to use combination of deviation in speed and electrical power output of the generator as input signals to PSS which operates simultaneously along with SVC. Such simultaneous PSS and SVC scheme is found to improve the damping under large disturbances i.e. the growth of system oscillations is arrested. The simulations are carried out on PSCAD.

S. V. Chandrakar [26], he analyze the performance of Radial basis function network (RBFN) based SVC on improvement in transient stability and damping of oscillations of the two machine system. This paper presents the comparative performance studies of two different controllers namely: [i] Conventional PI controller, and [ii] Radial basis function network (RBFN). The RBFN model is train by the voltage deviation signal.

S. Abaz S.Abazariari[27], he presents the application of a rule- based control scheme for an Advanced Static VAR Compensator (ASVC) to improve power system transient stability. The proposed method uses a current reference, based on the Transient Energy Function (TEF) approach. The proposed scheme provides, also, a continuous control of the reactive power owe.

A. S. Yome and N. Mithulananthan[28], he compares the shunt capacitor, SVC and STATCOM in static voltage stability improvement. Various performance measures are compared under different operating system conditions for the IEEE 14 bus test system. A methodology is also proposed to alleviate voltage control problems due to shunt capacitor compensation during lightly and heavily loaded conditions.

W. Zhang [29], he categorized the literature relevant to optimal allocation of shunt dynamic VAR source SVC and STATCOM, based on the voltage stability analysis tools used. Those tools include static voltage stability analysis ones such as P-V and V-Q curve analysis, continuation power flow (CPF), optimization methods (OPF), modal analysis, saddle-node bifurcation analysis, and dynamic voltage stability analysis ones such as Hopf bifurcation analysis and time-domain simulation.

L. Jose [30], he proposes a new type of single phase static compensator (STATCOM) for low rating used in customer side is proposed. This new STATCOM is constructed by cascading a full-bridge (H Bridge) voltage-source inverter (VSI’s) to the point of common coupling (PCC.) A so-called sinusoidal pulse width modulation (SPWM) unipolar voltage switching scheme is applied to control the switching devices of each VSI.

D.J. Hanson [31], the unbundling of the generation and transmission functions in England and Wales in England and Wales into separate shareholder-owned companies has inevitably resulted in far less predictability in terms of generator sitting and closure. National Grid, as the sole transmission company in England and Wales, is required to plan and respond quickly to changing system patterns to maintain both security and power quality standards.

A. S. Yome [32], he compares the shunt capacitor, SVC and STATCOM in static voltage stability improvement. Various performance measures are compared under different operating system condition for the IEEE 14 bus test system. Important issues related to shunt compensation, namely sizing installation location, for exclusive load margin improvement are addressed.

Mustapha Benghanem[33], presented a study of the dynamic performance analysis of an Advanced Static Var Compensator (ASVC) using a three-level voltage source inverter. The analysis is based on the modeling of the system in the d- q axis.

M. A. Abido[34], he presents a comprehensive review on the research and developments in the power system stability enhancement using FACTS damping controllers.

Anthony Johnson [35], the synchronized phasor measurements have only been used to monitor and analyze power system operations. However, synchrophasors have a much greater potential than just monitoring and visualization.

Mark Ndubuka N. [36], he investigates of the effects of Static Var Compensator (SVC) on voltage stability of a power system. The functional structure for SVC built with a Thyristor Controlled Reactor (TCR) and its model are described. The model is based on representing the controller as variable impedance that changes with the firing angle of the TCR. A Power System

Computer Aided Design /Electromagnetic Transients including DC (PSCAD/EMTDC) is used to carry out simulations of the system under study and detailed results are shown to access the performance of SVC on the voltage stability of the system.

1.3 MOTIVATION

Mitigation of power quality problems is synonymous with reduction of harmonic currents or voltage distortion at ac mains. These problems can also be mitigated by improving the immunity of the equipment using better quality material along with proper protection arrangements, but it may not result in an effective and economical solution.

1.4 OBJECTIVE

- Study different method already proposed for mitigation of harmonics due to non linear load.
- Design of synchronous reference frame (SRF)controller.
- Design, modeling and simulation of AC-DC Converter supply power connected to a R-L load using shunt passive filter for reactive power and harmonics compensation.
- Design, modeling and simulation of AC-DC Converter supply power system connected to a R-L load using a passive filter with thyristor controlled reactor (TCR) and thyristor switched capacitor (TSC) for reactive power and harmonics compensation.
- Develop the control algorithm for basic P-I controller used in hybrid passive filter.

1.5 THESIS LAYOUT

The present thesis embodies detailed investigations on different techniques of power quality improvement at ac mains in ac-dc converter with R-L load. The contents of the thesis have been divided into six chapters. A brief overview of each chapter is given as follows.

Chapter-1: deals with an introduction about the passive shunt filter. It also include comprehensive literature review of different topologies of passive filter and it control techniques. Also focus towards the motivation and objectives of the work.

Chapter-2: deals with different configuration of passive filters such as passive series filters, passive shunt filters are designed.

Chapter-3: different control strategy of passive shunt filter modeled and designed. SRF controller, TCR and TSC scheme with P-I controller were explained.

Chapter-4: deals with simulations results and discussion. A comparative analysis for passive shunt filter and without filter schemes was explained. TCR and TSC configuration is compared with passive shunt filter results.

Chapter-5: deals with conclusion and future scope of the work. It includes important reference for this project work.

INTRODCUTION TO PASSIVE FILTER

2.1 INTRODUCTON

The passive filters are used to mitigate power quality problems in six-pulse ac-dc converter with R-L load. Moreover, apart from mitigating the current harmonics, the passive filters also provide reactive power compensation, thereby, further improving the system performance. For current source type of harmonic producing loads, generally, passive shunt filters are recommended [43]. These filter apart from mitigating the current harmonics, also provide limited reactive power compensation and dc bus voltage regulation. However, the performance of these filters depends heavily on the source impedance present in the system, as these filter act as sinks for the harmonic currents. On the other hand, for voltage source type harmonic producing loads, the use of the series passive filters is recommended [43]. These filters block the flow of harmonic current into ac mains, by providing high impedance path at certain harmonic frequencies for which the filter is tuned. Moreover, the harmonic compensation is practically independent of the source impedance. But, passive filter suffer due to the reduction in dc link voltage due to the voltage drop across the filter components at both fundamental as well as harmonic frequencies.

This chapter presents a detailed investigation into the use of different configurations of passive filter such as passive shunt filter and passive series filters. The advantages and disadvantages of both configurations are discussed. It is observed that both these configuration fail to meet the IEEE standard 519 guidelines under varying load conditions. A novel configuration of passive hybrid filter (a combination of passive shunt and passive series filter) is designed and developed for power quality improvement. The main attraction of this configuration is that it can achieve the improved power quality even under varying load conditions, its rating is less and it can maintain that dc link voltage regulation within certain limits. The prototypes of these passive filters are developed and that test results are presented to verify the simulated results. Finally, a comparison of different power quality aspects in different configurations of passive filters is also presented for ac-dc converter with R-L load.

2.2 CLASSIFICATION OF PASSIVE FILTERS

Depending on the connection of different passive components, the passive filters can be broadly classified in three categories as given below.

2.2.1 Passive Shunt Filter

Fig.2.2 shows the schematic diagram of a passive shunt filter connected at input ac mains of six-pulse ac-dc converter with R-L load. This is the most commonly used configuration of passive filters. In this configuration different branches of passive tuned filters (low pass and high pass) tuned for the more dominant harmonics are connected in parallel with the diode rectifier with R-L load. It consists of a set of low pass tuned shunt filters tuned at 5^{th} and 7^{th} harmonic frequencies and high pass tuned for 11^{th} harmonic frequency. This passive filter scheme helps in sinking the more dominant 5^{th} and 7^{th} and other higher order harmonics and thus prevents them from flowing into ac mains. The diversion of harmonic current in the passive filter is primarily governed by the source impedance available in the system. The higher value of source impedance offers better performance of the passive filter.

2.2.2 Passive Series Filter

For voltage source type of harmonic loads (such as diode rectifier with R-L load filter), passive series filter is considered as a potential remedy for harmonic mitigation. Here, the different tuned branches of passive filters are connected in series with the supply and the diode rectifier. Fig.2.1 shows the schematic diagram of a passive series filter connected at input ac mains. It consists of a set of low block tuned shunt filter tuned at 5^{th} and 7^{th} harmonic frequencies and high block tuned filter for 11^{th} harmonic frequency. These passive filters blocks most dominant 5^{th}, 7^{th} and other higher order harmonics and thus prevents them from flowing into ac mains. Here, the performance of the series filter is not much dependent on the source impedance. However, it results in reduction in dc bus voltage due to voltage drop across filter components.

2.2.3 Passive Hybrid Filter

The use of passive shunt filter creates the problem of voltage regulation at light loads. It also increases the dc voltage ripple and ac peak current of the rectifier. On the other hand, passive series filter suffers from lagging power factor operation as well as the voltage drop across the filter components both at fundamental frequency as well as harmonic frequencies. To overcome these drawbacks, a combination of both these configurations is presented as passive hybrid filter. This configuration is able to supplement the shortfalls of both these passive filters and simultaneously it results in improvement in harmonic compensation characteristics for varying load condition even under stiff and distorted ac mains voltage.

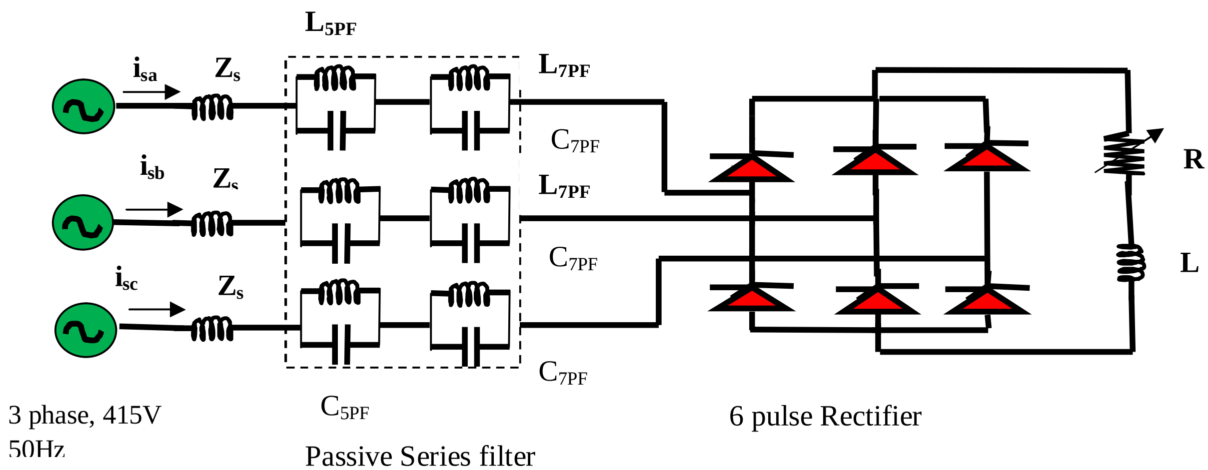

Fig.2.1 Schematic diagram of a ac-dc converter with R-L load and passive series filter at input.

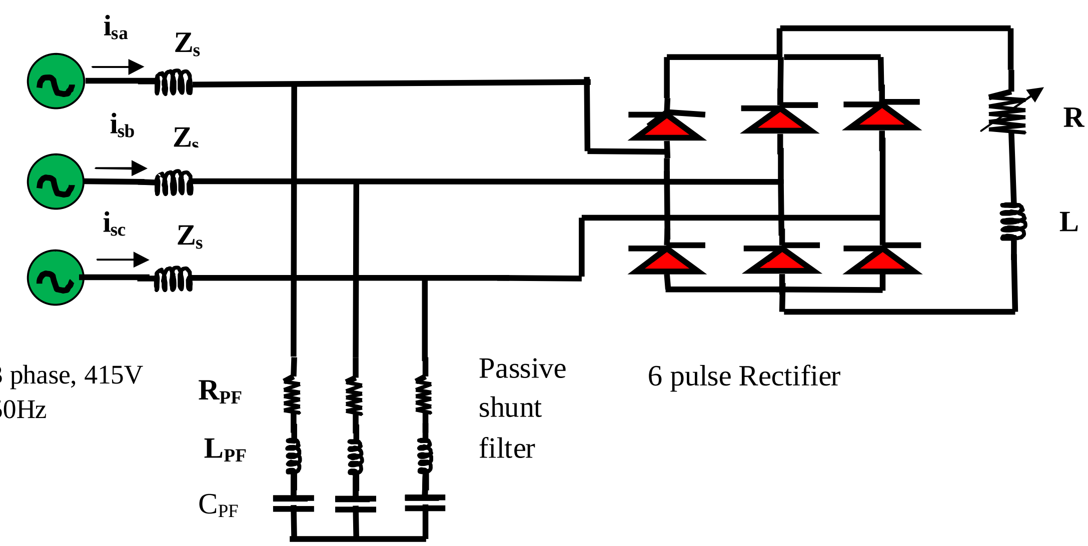

Fig.2.2 Schematic diagram of a six pulse ac-dc converter with R-L load and passive shunt filter at input

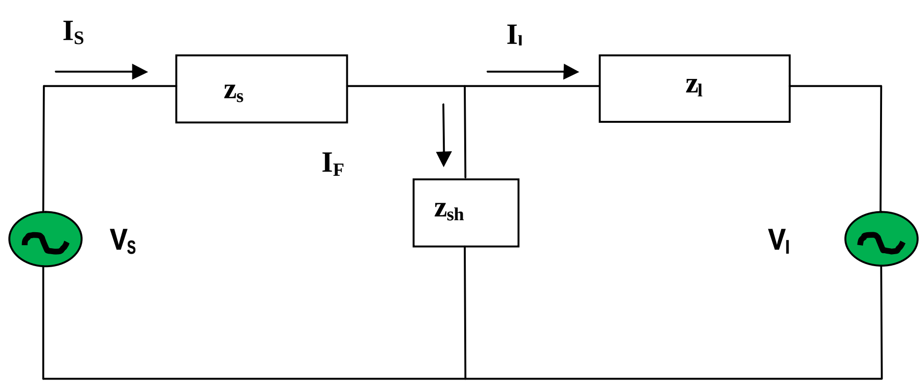

Fig.2.3 Equivalent circuit diagram of passive tuned shunt filter based configuration.

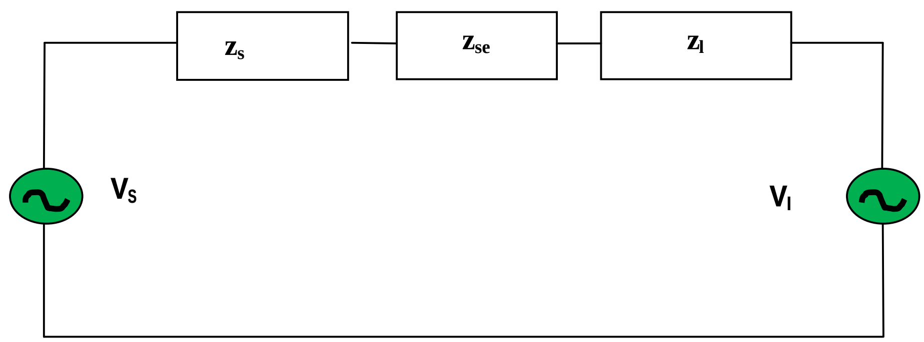

Fig.2.4 Equivalent circuit diagram of passive tuned series filter based configuration.

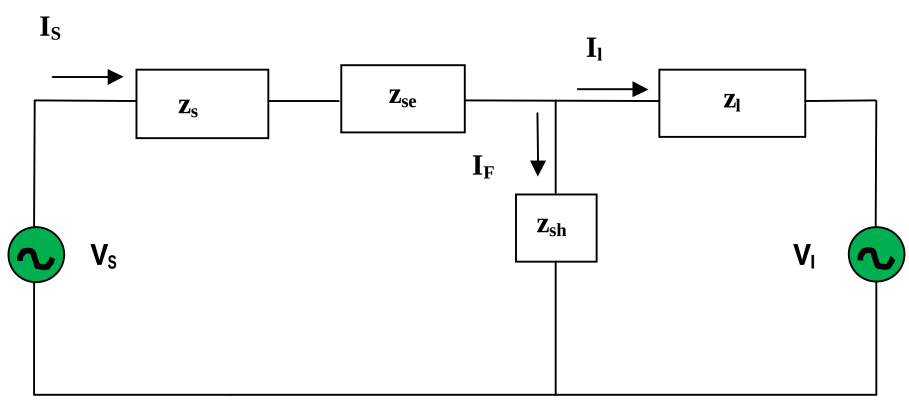

Fig.2.5 Fig.2.4 Equivalent circuit diagram of passive tuned series filter based configuration.

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2.3 COMPENSATION PRINCIPLE AND DESIGN OF PASSIVE FILTERS

The basic compensation principle and design procedure of different passive filter based configurations are given. In this work, mainly first order low pass filters and damped high pass filters are used for shunt configurations. For series configurations, single tuned first order filters and high block damped filters are used to form a composite filter.

2.3.1 Compensation Principle of Passive Shunt Filters

A passive shunt filter mainly consists of several LCR branches each tuned at a particular frequency. Fig.2.3 shows the equivalent circuit diagram of a passive tuned shunt filter.

The compensation characteristics of a passive shunt filter can be given as [43]

$$\frac{I_S}{V_l} = \frac{Z_{sh}}{Z_l Z_s + Z_{sh} + Z_s Z_{sh}} \tag{2.1}$$

Where 'Z_{sh}' is the impedance of parallel LC filter. As it can be seen from eqn. (2.1), that the performance of parallel LC filter greatly depends on the source impedance and is determined only by the ratio of the source impedance and the filter impedance.

If Z_l =0, then from eqn. (2.1), I_s =I_l, which means that the passive filter is not effective. On the other hand, if Z_s=0, then, $\frac{I_s}{V_l} = \frac{1}{Z_l}$, which means that the filter does not provide harmonic compensation.

It is seen that the filter interaction with the source impedance results in a parallel resonance. For inductive source impedance (Z_s), this occurs at a frequency below the frequency at which the filter is tuned. It is given as:

$$f_{sys} = \frac{1}{2\pi(L_s + L)C} \tag{2.2}$$

Moreover, if a filter is exactly tuned at a frequency of concern, then an upward shift in the tuned frequency results in a sharp increase in impedance as seen by the harmonic. The most common mechanisms that may cause filter detuning are:

- Capacitor fuse-blowing, which lowers the total capacitance, thereby raising the frequency at the filter has been tuned.
- Manufacturing tolerances in both inductor as well as capacitor.
- Temperature variations.
- System parameter variations

Therefore, generally, the filter banks are tuned to around 6%below the desired frequency as per IEEE standard 1531[45].

2.3.2 Compensation Principle of Passive Series Filters

Here, the harmonic compensation is achieved by blocking specific harmonic current with the parallel tuned LCR circuits. Fig. 3 shows the equivalent circuit diagram of a passive tuned series filter.

The compensation characteristics of a passive series filter can be given as [43]

$$\frac{I_S}{V_l} = \frac{1}{Z_s + Z_{se} + Z_l} \qquad (2.3)$$

Eqn. (2.3) shows that the harmonic compensation performance of the series filter is virtually independent of the source impedance, since the source impedance is relatively small compared to the LC filter impedance at harmonic frequencies.

2.3.3 Design of passive filters

Various issues involved with the design of the passive filters are considered here. The design procedure of passive filter is explained in detail.

2.3.4Filter design constraints

There are various issues in the design of a passive filter for its proper functioning in harmonic reduction. The key issues are mentioned here:

- Minimizing harmonic source current

The prime objective of the filter design is to minimize the harmonic current in ac mains. This is ensured by minimizing the filter impedance at the harmonic frequencies so that the harmonic filter acts as a sink for the harmonic currents.

- Minimizing fundamental current in passive filter

To ensure that the installation of passive filter does not cause the system loading, the fundamental current in the passive filter is minimized by the maximizing the passive filter impedance at the fundamental frequency.

- Environment and ageing effect

The capacitors with metalized film construction lose capacitance as they age. Similarly the manufacturer tolerance of the harmonic filter reactor may result in tuned frequency higher than the nominal. An IEEE Standard 1531[45] recommends that the passive filters are tuned at 6% below the rated frequency so that it will exhibit acceptable tuning at the end of its 20 year life.

2.3.5 Design of Passive Shunt Filter

The passive shunt filter consists of first order series tuned low pass filters for 5^{th} and 7^{th} order harmonics. For the series tuned low pass filters, the impedance is given by:

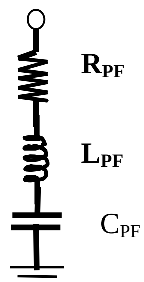


Fig.2.6 Low pass Filter

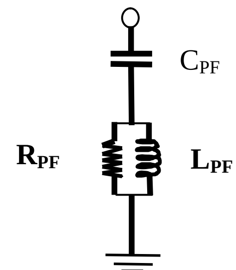


Fig.2.7 High pass Filter

$$Z_{sh(h)} = \left[R + j\left(hX_L - \frac{X_C}{h} \right) \right] \tag{2.4}$$

$$\left.\begin{aligned} X_L &= \frac{X_C}{h_n^2} \\ X_c &= \left(\frac{h_n^2 - 1}{h_n^2} \right) \frac{V^2}{Q_{sh}} \end{aligned}\right\} \tag{2.5}$$

Where Q_{sh} is the reactive power provided by the passive filter, h is the harmonic order of the passive filter; X_L is the reactance of inductor. X_c is the reactance of the capacitor at fundamental frequency. The reactive power requirement may be initially assumed around 25% of the rating of the load [44]. It may be equally divided among different filter branches. The values of series tuned elements may be calculated from eqn. (2.5). The quality factor for low pass filter (defined as QF $=X_L/R$), is consider as 30 in this work to calculate the value of the resistive element.

The resonant frequency for the h^{th} harmonic is given as:

$$f_h = \frac{1}{(2\pi hCR)} \tag{2.6}$$

Quality factor can be defined as $Q = \frac{L}{(CR^2)}$ (2.7)

The values of filter components can be calculated from above equations.

2.4 SUMMARY

The design of the passive shunt filter is carried out as per the reactive power requirements. This filter is designed to compensate the requirements of reactive power of the system. Therefore, this passive filter helps in maintaining the dc link voltage regulation within limits along with the power factor improvement. It also sinks the harmonic currents of frequencies at which the passive filters have been tuned.

CONTROL TECHNIQUES APPLIED TO PSF

3.1 SRF CONTROLLER

The synchronous reference frame theory or d-q theory is based on time-domain reference signal estimation techniques. It performs the operation in steady-state or transient state as well as for generic voltage and current waveforms. It allows controlling the active power filters in real time system. Another important characteristic of this theory is the simplicity of the calculations, which involves only algebraic calculation. The basic structure of SRF controller consists of direct (d-q) and inverse $(d\text{-}q)^{-1}$ park transformations as shown in fig.1. These can useful for the evaluation of a specific harmonic component of the input signals [46].

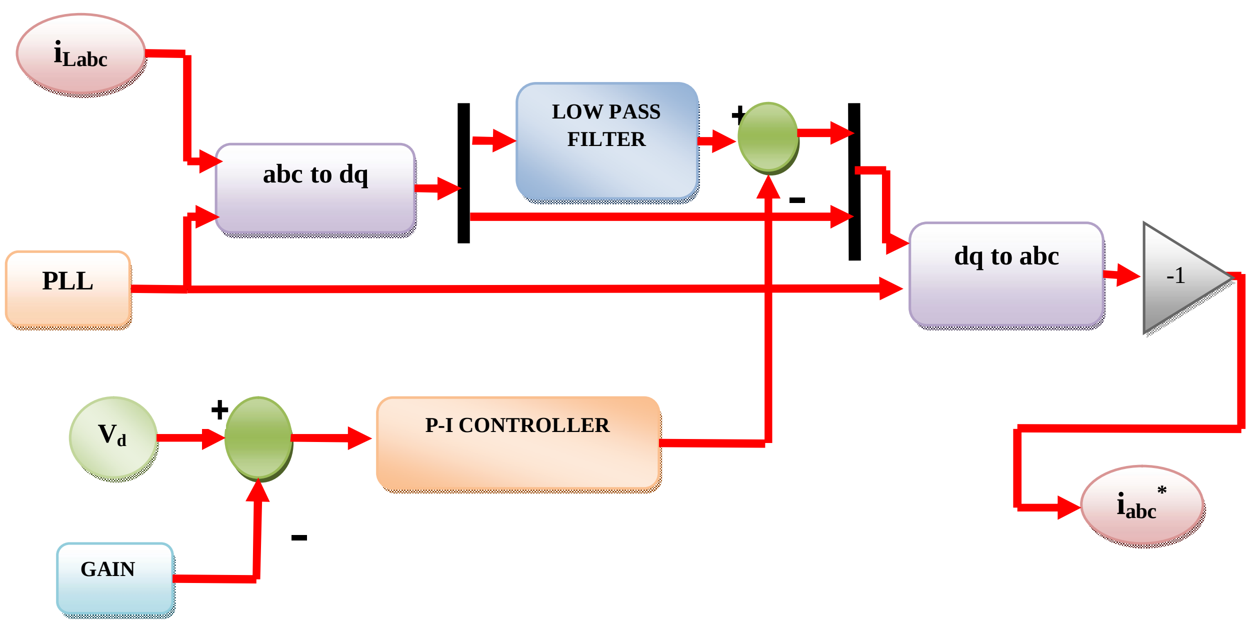


Fig.3.1 Synchronous d-q-0 reference frame based compensation algorithm

The reference frame transformation is formulated from a three-phase a-b-c stationary system to the direct axis (d) and quadratic axis (q) rotating co-ordinate system. In a-b-c, stationary axes are separated from each other by 120^0 as shown in fig. 2. The instantaneous space vectors, V_a and i_a are set on the a-axis, V_b and i_b are on the b-axis, similarly V_c and i_c are on the c-axis.

These three phase space vectors stationary coordinates are easily transformed into two axis d-q rotating reference frame transformation. This algorithm facilitates deriving i_d-i_q(rotating current coordinate) from three phase stationary coordinate load current $i_{La}.i_{Lb},i_{Lc}$, as shown in equation

$$\begin{pmatrix} i_{Ld} \\ i_{Lq} \\ i_{L0} \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} \cos\theta & \cos\left(\theta - {2\pi}/{3}\right) & \cos\left(\theta + {2\pi}/{3}\right) \\ \sin\theta & \sin\left(\theta - {2\pi}/{3}\right) & \sin\left(\theta + {2\pi}/{3}\right) \\ {1}/{\sqrt{2}} & {1}/{\sqrt{2}} & {1}/{\sqrt{2}} \end{pmatrix} \begin{pmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{pmatrix} \tag{3.1}$$

The d-q transformation output signals depend on the load current (fundamental and harmonic components) and the performance of the Phase Locked Loop (PLL). The PLL circuit provides the rotation speed (rad/sec) of the rotating reference frame, where ωt is set as fundamental frequency component. The PLL circuit provides the vectorized 50 Hz frequency and 30^0 phase angle followed by sinѳ and cosѳ for synchronization. The i_d-i_q current are sent through low pass filter (LPF) for filtering the harmonic components of the load current, which allows only the fundamental frequency components. The LPF is a second order Butterworth filter, whose cut off frequency is selected to be 50 Hz for eliminating the higher order harmonics. The P-I controller is used to eliminate the steady-state error of the DC component of the d-axis reference signals. Furthermore, it maintains the capacitor voltage nearly constant. The DC side capacitor voltage of PWM-voltage source inverter is sensed and compared with desired reference voltage for calculating the error voltage. This error voltage is passed through a P-I controller whose propagation gain (K_P) and integral gain (K_I) is 0.1 and 1 respectively.

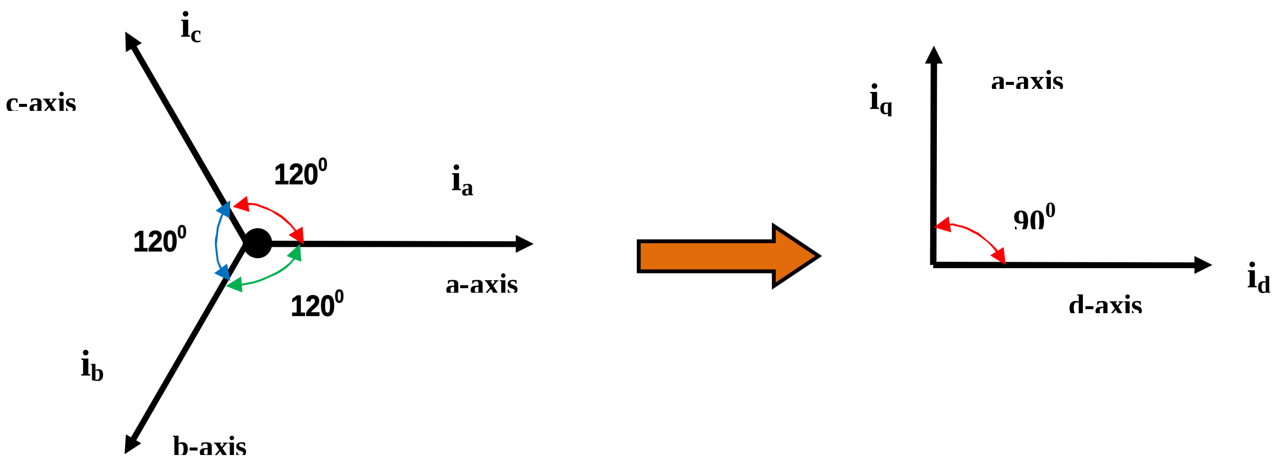


Fig.3.2 a-b-c to d-q-0 transformation

3.2 THYRISTOR-CONTROLLED REACTOR (TCR) AND THYRISTOR SWITCH CONTROL (TSC)

3.2.1 INTRODCTION

A TCR is one of the most important building blocks of thyristor-based SVCs.Although it can be used alone,it is more often employed in conjuction with fixed or thyristor-switched capacitors to provide rapid,continuous control of reactive power over the entire selected lagging-to-leading range.

3.2.2 Single-Phase TCR

A basic single phase TCR comprises an anti-parallel connected pair of thyristor valves,T_1 and T_2,in series with a linear air-core reactor,shown in fig.The antiparallel thyristor pair acts like a bidirectional switch,with thyristor valve T_1 conducting in positive half-cycles and thyristor T_2 conducting in negative half-cycles of the supply voltage.The firing angle of the thyristors is measured from the zero crossing of the voltage appearing across its terminal.

The controllable range of the TCR firing angle, α ,extends from 90^o to 180^o.The continuous sinusoidal current flow in the TCR but as α range, the current reduces to zero for a firing angle of 180^o and below 90^o ,it introduce a dc current , disturbing the symmetrical operation of the two antiparallel valve branches.

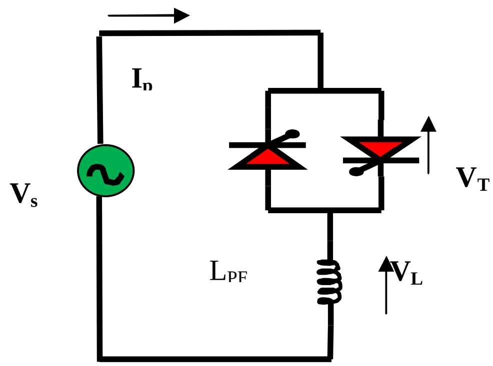


Fig.3.3 Circuit diagram of TCR

The basic modeling of single phase TCR can be as follows. The source source voltage as:

$$V_s(t) = V \sin \omega t$$

From the basic Kirchhoffs voltage equation, we can modeled as fig.3.2.

$$L\frac{di}{dt} - V_s(t) = 0 \tag{3.2}$$

Where V=peak value of the applied voltage , ω= the angular frequency of the supply voltage and L= inductance of the TCR, then the line current can be written as

$$i(t) = \frac{1}{L}\int V_s(t)dt + C \tag{3.3}$$

$$i(t) = -\frac{V}{\omega L}\cos \omega t + C \tag{3.4}$$

For the boundary condition is $i(\omega t = \alpha) = 0$,

$$i(t) = -\frac{V}{\omega L}(\cos\alpha - \cos\omega t) \tag{3.5}$$

Where α=is the firing angle measured from posive going zero crossing of the applied voltage. The Fourier analysis equation (3.5) can be written as

$$I(\alpha) = a_1 \cos\omega t + b_1 \sin\omega t \tag{3.6}$$

Where b_1=0, because of odd symmetry i.e, $f(x) = f(-x)$.Also no even harmonics are generated because of half wave symmetry i.e $f\left(x + T/2\right) = -f(x)$

The coefficient a_1 is given by

$$a_1 = \frac{4}{T}\int_0^{T/2} f(x)\cos\frac{2\pi x}{T}\,dx \tag{3.7}$$

Solving,

$$I_1(\alpha) = \frac{V}{\omega L}\left(1 - \frac{2\alpha}{\pi} - \frac{1}{\pi}\sin 2\alpha\right) \tag{3.8}$$

The equation (7) can be written as

$$I_1(\alpha) = VB_{TCR}(\alpha) \tag{3.9}$$

Where

$$B_{TCR}(\alpha) = B_{\max}\left(1 - \frac{2\alpha}{\pi} - \frac{1}{\pi}\sin 2\alpha\right) \tag{3.10}$$

Where $B_{\max} = \dfrac{1}{\omega L}$

The TCR is act like a variable susceptance.Variation of firing angle changes the susceptance and consequently the fundamental-current component which leads to a variation of reactive power absorbed by the reactor because the applied ac voltage is constant.

3.2.3 TSC

It consists of capacitor in series with bidirectional thyristor switch. It is supplied from a ac voltage source. The analysis of the current transients after closing the switch brings two cases:

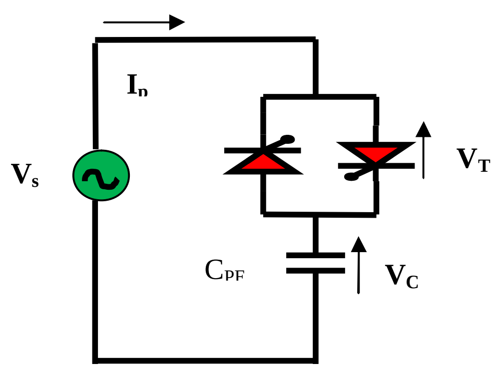


Fig.3.4 Circuit diagram of TSC

1. The capacitor voltage is not equal to the supply voltage when the thyristors are fired. Immediately after closing the switch, a current of infinite magnitude flows and charges the capacitor to the supply voltage in an infinitely short time. The switch realized by the thyristor cannot withstand this stress and would fail.

2. The capacitor voltage is equal to the supply voltage when the thyristors are fired. The current will jump immediately to the value of the steady-state current. Although the magnitude of the current does not exceed the steady-state values, the thyristor have an upper limit of $\frac{di}{dt}$ that they

can withstand during the firing process. Here $\frac{di}{dt}$ is infinite, and the thyristor switch will again fail.

3.2.4 TCR-TSC COMBINATION

The TCR-TSC comprises usually n-series of TSC and single TCR that are connected in parallel. The capacitor can be switched in discrete steps, whereas continuous control within the reactive-power span of each step is provided by TCR.

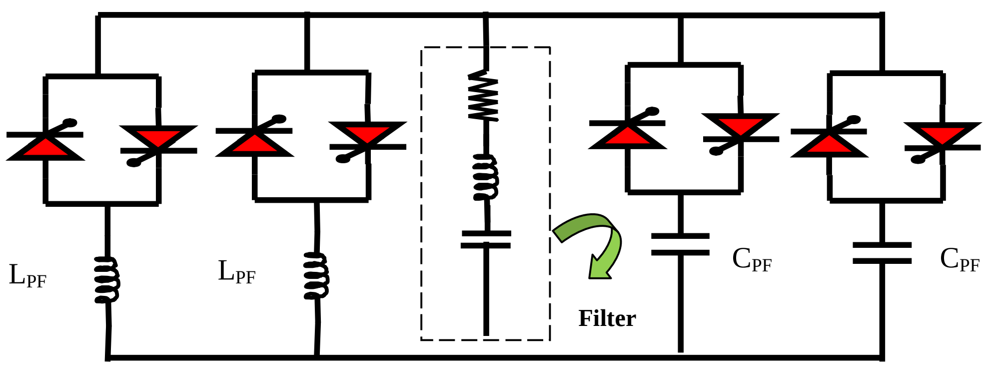


Fig.3.5 Circuit diagram of TCR-TSC Combination

As the size of TCR is small the harmonic generation is substantially reduced. The TSC branches are tuned with series reactor to different dominant harmonic frequencies.

The main motivations in developing TCR_TSC were for enhancing the operational flexibility of the compensator during large disturbances and for reducing the steady-state losses.

What particularly aggravate the problem in which severe voltage swings are experienced and followed by the load rejection. But TCR-TSC can quickly operate to disconnect all the capacitor from the compensator,producing resonant oscillations.

The proposed configuration for passive shunt filter with TCR and TSC is shown in fig.3.6.

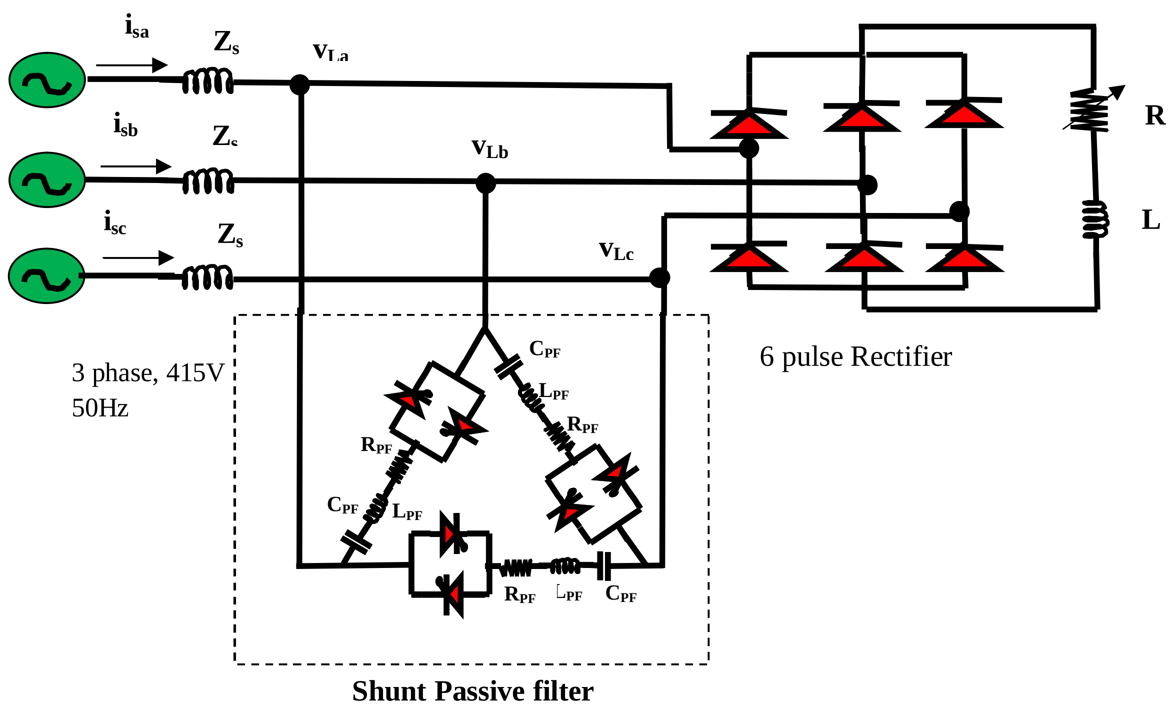


Fig. 3.6 Proposed Configuration for passive shunt filter with TCR and TSC combination.

3.2.5 EXTRACTION OF FIRING ANGLE 'α'

The reflected reactance can be modeled and its value as a function of firing angle for two types of connection that is star and delta connection.

The equivalent inductance of the star connection is given by

$$L_{PF}(\alpha) = L_{PF} \frac{\pi}{2\pi - 2\alpha + \sin(2\alpha)} \tag{3.11}$$

Where the firing angle is bounded as $\left(\pi/2\right) \le \alpha \le \pi$

The equivalent delta inductance is given by

$$L_{PF}(\alpha) = L_{PF} \frac{\pi}{2\pi - 2\left(\alpha + \frac{\pi}{6}\right) + \sin 2\left(\alpha + \frac{\pi}{6}\right)} \tag{3.12}$$

Where the firing angle is bounded as $\left(\pi/3\right) \le \alpha \le \left(5\pi/6\right)$

The delta connection susceptance is

$$B(\alpha) = B \frac{2\pi - 2\left(\alpha + \frac{\pi}{6}\right) + \sin\left(2\left(\alpha + \frac{\pi}{6}\right)\right)}{\pi} \tag{3.13}$$

Where $B = 1/L_{PF\omega_0}$

The total reactive power of filter is

$$Q_{PF}(\alpha) = 3V^2\left(B_C - B_L(\alpha)\right) \tag{3.14}$$

Where $B_L(\alpha) = 1/X_L(\alpha)$ and $B_C = 1/X_C$

3.3 MODELING AND DESIGN OF PASSIVE FILTER WITH TCR

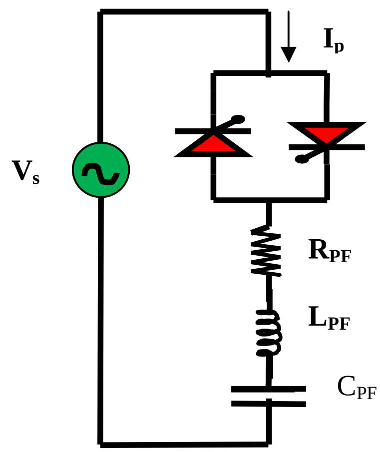


Fig.3.7 Circuit diagram of TCR-TSC Combination.

3.3.1Modeling of Passive Filter with TCR-TSC Combination

Kirchhoff's law equation in Stationary reference frame

$$V_{sk} = L_{PF}\frac{di_p}{dt} + R_{PF}i_p + \frac{1}{C_{PF}}\int i_p dt \qquad (3.15)$$

For k=1, 2, 3

Differentiating (3.15) once result in

$$\frac{dV_{sk}}{dt} = L_{PF}\frac{d^2 i_p}{dt^2} + R_{PF}\frac{di_p}{dt} + \frac{i_p}{C_{PF}} \qquad (3.16)$$

3.3.2Model Transformation into "d-q" reference frame

The system is transformed into the synchronous orthogonal frame rotating at the constant supply frequency ω.The matrix conversion is

$$C_{dq}^{123} = \sqrt{\frac{2}{3}}\begin{bmatrix} \cos\theta & \cos\left(\theta - 2\pi/3\right) & \cos\left(\theta - 4\pi/3\right) \\ -\sin\theta & -\sin\left(\theta - 2\pi/3\right) & -\sin\left(\theta - 4\pi/3\right) \end{bmatrix} \tag{3.17}$$

The equation (3.16) can be rewritten as

$$\frac{d^2}{dt^2}\left[i_p\right] = -\frac{R_{PF}}{L_{PF}}\frac{d}{dt}\left[i_p\right] - \frac{1}{C_{PF}L_{PF}}\left[i_p\right] + \frac{dV_s}{dt} \tag{3.18}$$

The following reduced transformation matrix can be used as

$$C_{dq}^{123} = \sqrt{2}\begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\left(\theta - \pi/6\right) & \cos\left(\theta - \pi/6\right) \end{bmatrix} \tag{3.19}$$

Applying these transformations into (3.18), then

$$\frac{d^2}{dt^2}\left[C_{dq}^{12}\left[i_{dq}\right]\right] = -\frac{R_{PF}}{L_{PF}}\frac{d}{dt}\left[C_{dq}^{12}\left[i_{dq}\right]\right] - \frac{1}{L_{PF}}\left[C_{dq}^{12}\left[i_{dq}\right]\right] - \frac{1}{L_{PF}}\frac{d}{dt}\left[C_{dq}^{12}\left[v_{dq}\right]\right] \tag{3.20}$$

$$\frac{d}{dt}\left[C_{12}^{dq}\left[i_{dq}\right]\right] = C_{12}^{dq}\frac{d}{dt}\left[i_{dq}\right] + \left(\frac{d}{dt}C_{12}^{dq}\right)\left[i_{dq}\right] \tag{3.21}$$

$$\frac{d^2}{dt^2}\left[C_{12}^{dq}\left[i_{dq}\right]\right] = C_{12}^{dq}\frac{d^2}{dt^2}\left[i_{dq}\right] + \left(\frac{d}{dt}C_{12}^{dq}\right)\frac{d}{dt}\left[i_{dq}\right] + \left(\frac{d}{dt}C_{12}^{dq}\right)\frac{d}{dt}\left[i_{dq}\right] + \left(\frac{d^2}{dt^2}C_{12}^{dq}\right)\left[i_{dq}\right] \tag{3.22}$$

$$\frac{d}{dt}\left[C_{12}^{dq}\left[V_{dq}\right]\right] = C_{12}^{dq}\frac{d}{dt}\left[V_{dq}\right] + \left(\frac{d}{dt}C_{12}^{dq}V_{dq}\right) \tag{3.23}$$

$$\frac{d^2}{dt^2}\left[i_{dq}\right]=-\begin{bmatrix}\frac{R_{PF}}{L_{PF}} & -2\omega \\ 2\omega & \frac{R_{PF}}{L_{PF}}\end{bmatrix}\frac{d}{dt}\left[i_q\right]-\begin{bmatrix}-\omega^2+\frac{1}{C_{PF}L_{PF}} & -\omega\frac{R_{PF}}{L_{PF}} \\ \omega\frac{R_{PF}}{L_{PF}} & -\omega^2+\frac{1}{C_{PF}L_{PF}}\end{bmatrix}\left[i_{dq}\right]$$

$$+\frac{1}{L_{PF}}\frac{d}{dt}\left[V_{dq}\right]+\frac{1}{L_{PF}}\begin{bmatrix}0 & -\omega \\ \omega & 0\end{bmatrix}\left[V_{dq}\right] \tag{3.24}$$

Finally, the dynamic model in ‘d-q’ frame as

$$L_{PF}\frac{d^2 i_d}{dt^2}=-R_{PF}\frac{di_d}{dt}+2\omega L_{PF}\frac{di_q}{dt}-\left(-\omega^2 L_{PF}+\frac{1}{C_{PF}}\right)i_d+\omega R_{PF}i_q+\frac{dV_d}{dt}-\omega V_q \tag{3.25}$$

$$L_{PF}\frac{d^2 i_q}{dt^2}=-R_{PF}\frac{di_q}{dt}+2\omega L_{PF}\frac{di_d}{dt}-\left(-\omega^2 L_{PF}+\frac{1}{C_{PF}}\right)i_q+\omega R_{PF}i_d+\frac{dV_q}{dt}-\omega V_d \tag{3.26}$$

The eqn. (3.25) and (3.26) can be written as follows.

$$L_{PF}\frac{d^2 i_d}{dt^2}+R_{PF}\frac{di_d}{dt}+\left(-\omega^2 L_{PF}+\frac{1}{C_{PF}}\right)i_d=2\omega L_{PF}\frac{di_q}{dt}+\omega R_{PF}i_q+\frac{dV_d}{dt}-\omega V_q \tag{3.27}$$

$$L_{PF}\frac{d^2 i_q}{dt^2}+R_{PF}\frac{di_q}{dt}+\left(-\omega^2 L_{PF}+\frac{1}{C_{PF}}\right)i_q=-2\omega L_{PF}\frac{di_d}{dt}+\omega R_{PF}i_d+\frac{dV_q}{dt}-\omega V_d \tag{3.28}$$

3.4 MODELING AND DESIGN OF P-I CONTROLLER

3.4.1 INTRODUCTION

The usefulness of PI control lies in their general applicability to most control systems. When the mathematical model of the plant is not known and therefore analytical design methods cannot be used, PI controls prove to be most useful. In practical cases, there may be one requirement on the response to disturbance input and another requirement on the reference input. Often these two requirements conflict with each other and cannot be satisfied in the single-degree-of-freedom case. By increasing the degrees of freedom, it can be reach up to the satisfaction of both. Finally, a very powerful computational approach with MATLAB to search optimal sets of parameter values to satisfy given transient response specifications(such as that the maximum overshoot in the response to the unit-step reference input be less than a specified value and the settling time be less than a specified value). This approach can be directly applied to the design of high-performance control systems.

The proportional control will reduce the steady-state error, but at the cost of a larger overshoot. Furthermore, proportional gain will never completely eliminate the steady-state error. For that we need to try integral control. The K_i controller really slows down the response. To reduce the settling time, we can increase K_i , but by doing this, the transient response will get worse (e.g. large overshoot).

3.4.2 Design of P-I Controllers

The standard approach to design is this: a mathematical model is built making necessary assumptions about various uncertain quantities on the dynamics of the system. If the objective s well defined in precise mathematical terms, then control strategies can be derived mathematically (e.g., by optimizing some criterion of the performance).

The control law is applied to the dynamic model equation (3.27) and (3.28)

For making system equation (3.27) and (3.28) linear, we substitute the two input variables u_d and u_q such

$$u_d = 2\omega L_{PF}\frac{di_q}{dt} + \omega R_{PF} i_q + \frac{dV_d}{dt} - \omega V_q \tag{3.29}$$

$$u_q = -2\omega L_{PF}\frac{di_d}{dt} + \omega R_{PF} i_d + \frac{dV_q}{dt} - \omega V_d \tag{3.30}$$

The input transformation given in the (3.29) and (3.30), the coupled dynamics of the tracking problem have been transformed into decoupled dynamics. Thus the system equation (3.29) and (3.30) becomes linear one.

The corresponding transfer functions are:

$$\frac{i_d}{u_d} = \frac{1}{L_{PF}s^2 + R_{PF}s + \frac{1}{C_{PF}} - L_{PF}\omega^2} \quad \text{...(3.31)}$$

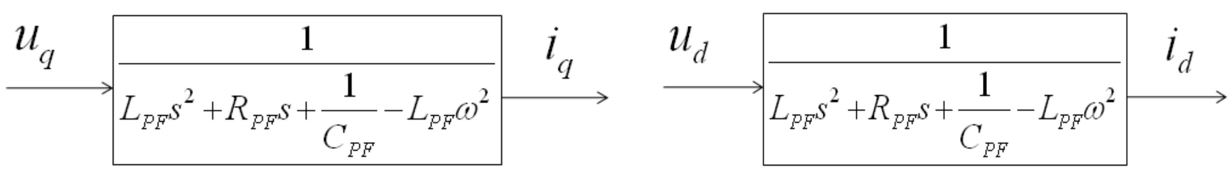


Fig.3.8 Block diagram of the closed loop system.

By using error signals $\tilde{i}_d = i_d^* - i_d$ and $\tilde{i}_q = i_q^* - i_q$ then applying P-I compensation u_d and u_q are chosen such that

$$u_d = k_p\tilde{i}_d + k_i\int \tilde{i}_d\,dt$$

$$u_q = k_p \tilde{i}_q + k_i \int \tilde{i}_q dt \tag{3.32}$$

The transfer function of the P-I controllers is given as

$$G(s) = \frac{U_q(s)}{\tilde{I}_q(s)} = \frac{U_d(s)}{\tilde{I}_d(s)} = k_p + \frac{k_i}{s} \tag{3.33}$$

And the closed-loop transfer function of the current loop is

$$\frac{I_q(s)}{\tilde{I}_q(s)} = \frac{I_d(s)}{\tilde{I}_d(s)} = \frac{k_p}{L_{PF}} \cdot \frac{s + \frac{k_i}{k_p}}{s^3 + \frac{R_{PF}}{L_{PF}} s^2 + \left(\frac{1}{C_{PF} L_{PF}} - \omega^2 + \frac{k_p}{L_{PF}} \right) s + \frac{k_p}{L_{PF}}} \tag{3.34}$$

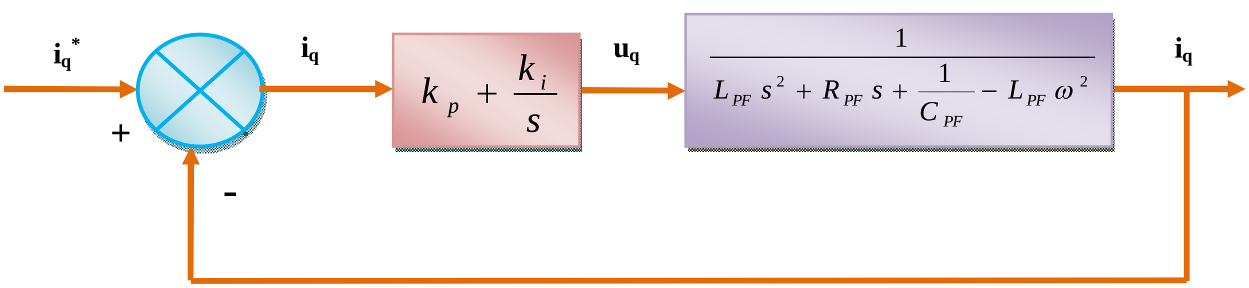


Fig.3.9 Block diagram of the closed loop system in q-axis.

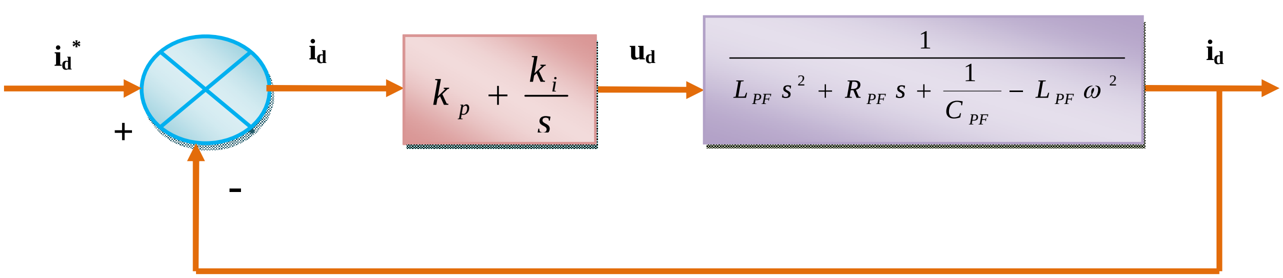


Fig.3.10 Block diagram of the closed loop system in d-axis.

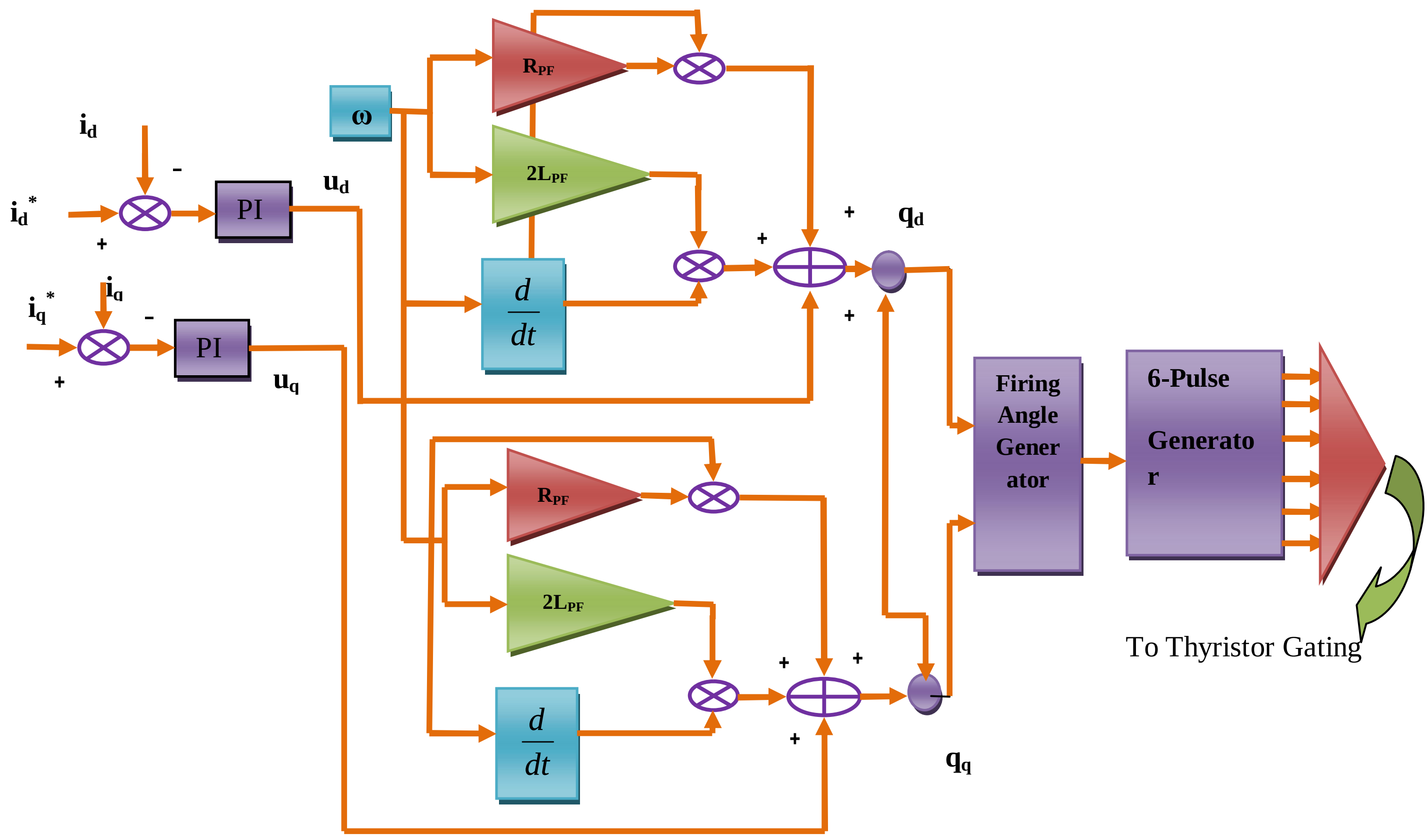


Fig. 3.11 P-I Controller diagram

3.5 SUMMARY

This chapter explains the transformation theory for conversion of three phase parameters to two-phase and vice versa. Detail modeling of the TCR-TSC configuration is analyzed in this chapter. The control strategy with P-I controller is also explained.

RESULTS AND DISCUSSION

4.1 SIMULATION RESULTS

The simulation results are obtained through Power System toolboxes in SIMULINK by taking system parameter as given below.

4.1.1 System Parameters

The system parameters considered for the study of Passive shunt filter with TCR and TSC combination is given below in Table 4.1.

TABLE 4.1. Specification for Test System

Components	Specifications
AC Source	V_s=415v, f=50 Hz
Nonlinear Load	Three-phase Thyristor Rectifier R_L=40(Ω) L_L=50(mH)
Passive Filter	L_{PF}=16(mH),R_{PF}=0.83(Ω),C_{PF}=25(μF)

4.2 MATLAB BASED MODELING OF PASSIVE FILTER

To demonstrate the performance of these passive filters feeding a three-phase converter with R-L load, these passive filters are modeled in MATLAB environment along with SIMULINK and power system block set toolboxes. Different components of these converters such as low pass filter with R-L load are simulated in MATLAB/SIMULINK.

4.2.1 Passive Shunt Filter Based Converter with R-L Load

Fig. shows the MATLAB model of a passive series filter based six pulse ac-dc converters with R-L load. Depending on the harmonic spectrum of the supply current, the passive filters designed are low pass filter tuned for 5th order harmonic frequency. The subsystem named shunt filter consists of 5th harmonic frequency. Based on the design carried out the filter component values are L=16mH, C=25μF, R=0.83Ω.

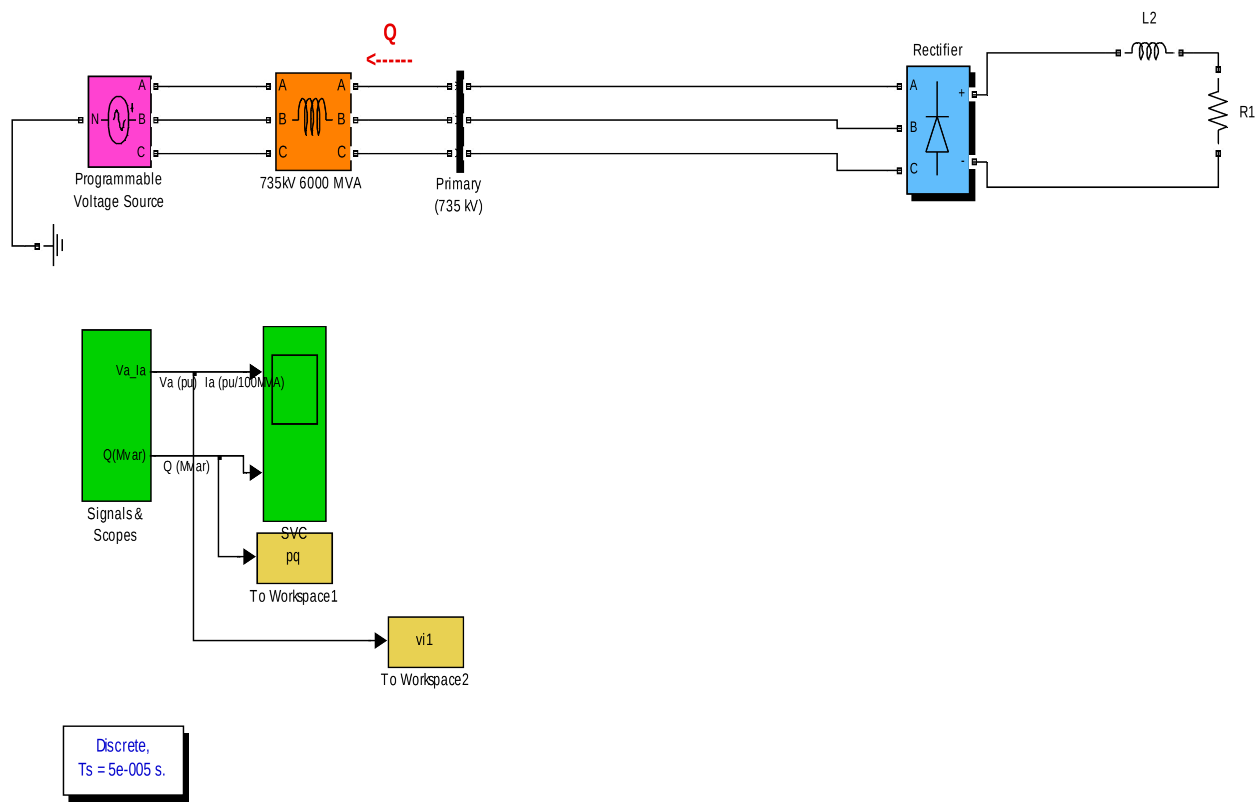


Fig.4.1 MATLAB based model of a six pulse ac-dc converter R-L load without passive filter.

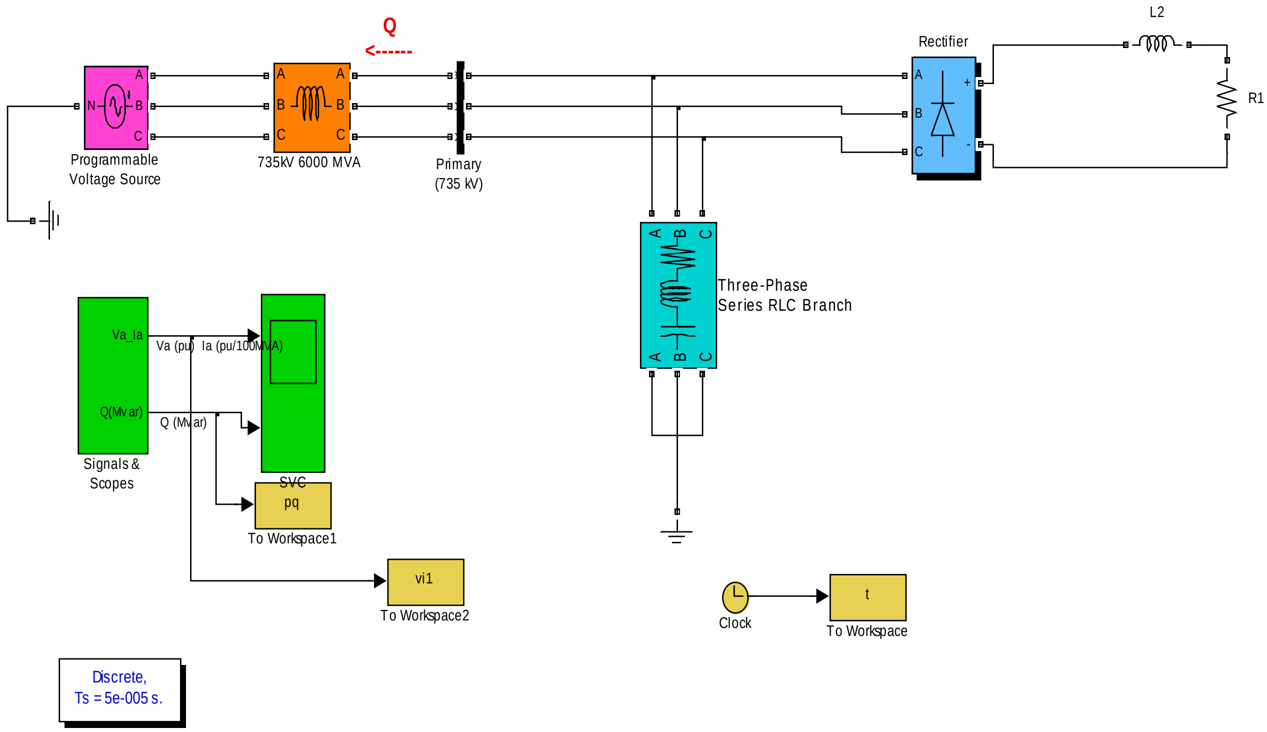


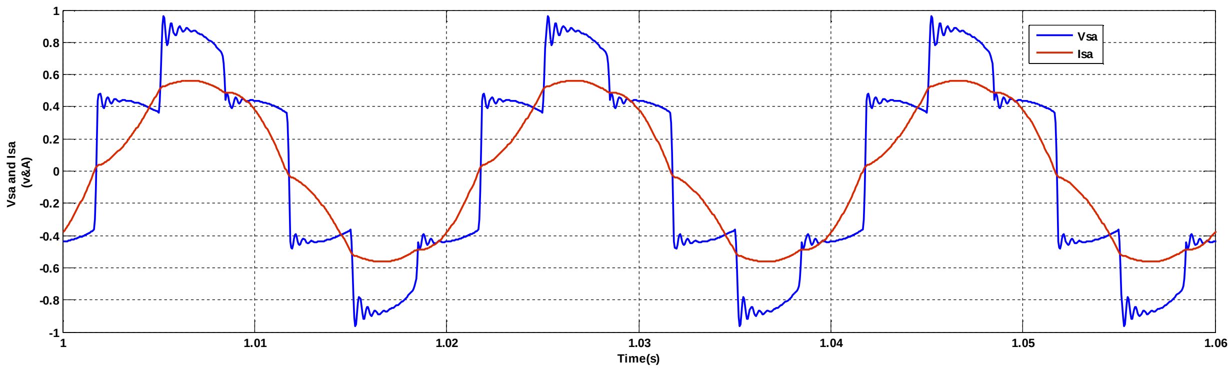
Fig. 4.2 MATLAB based model of a six pulse ac-dc converter R-L load with passive shunt filter.

4.2.2 Results and Discussion

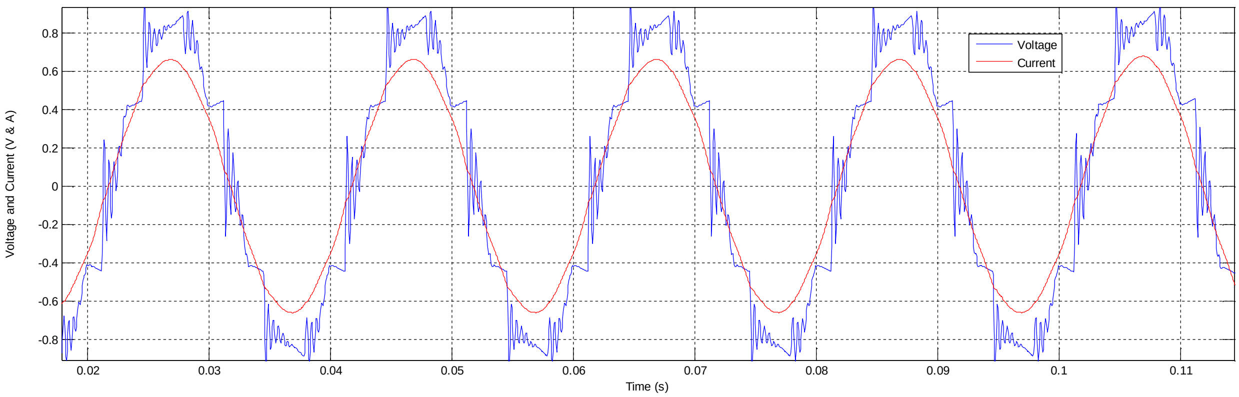
The configuration of passive shunt filter has been simulated and developed for six pulse ac-dc converter with R-L load. The simulated and test results of with passive shunt filter and without passive shunt filter configurations are presented here. To compare the performance of a six pulse converter R-L load with passive shunt filter and without passive shunt filter is presented and discussed.

4.2.3 Performance of Passive Shunt Filter based ac-dc Converter with R-L Load

The performance of passive shunt filter based converter wit R-L load is shown in Fig. The dynamic response of the passive shunt filter based converter is shows in Fig. It shows the waveforms of supply voltage V_s, voltage at point of common coupling (PCC) V_{pcc}, supply current i_s, load current i_l, filter current i_{sh} and the dc link voltage V_{dc}(V). It can be observed that the supply current wave form improves as the shunt filter is switched on. The passive filter has been designed such that the rms current drawn from the ac mains is less than the load current.

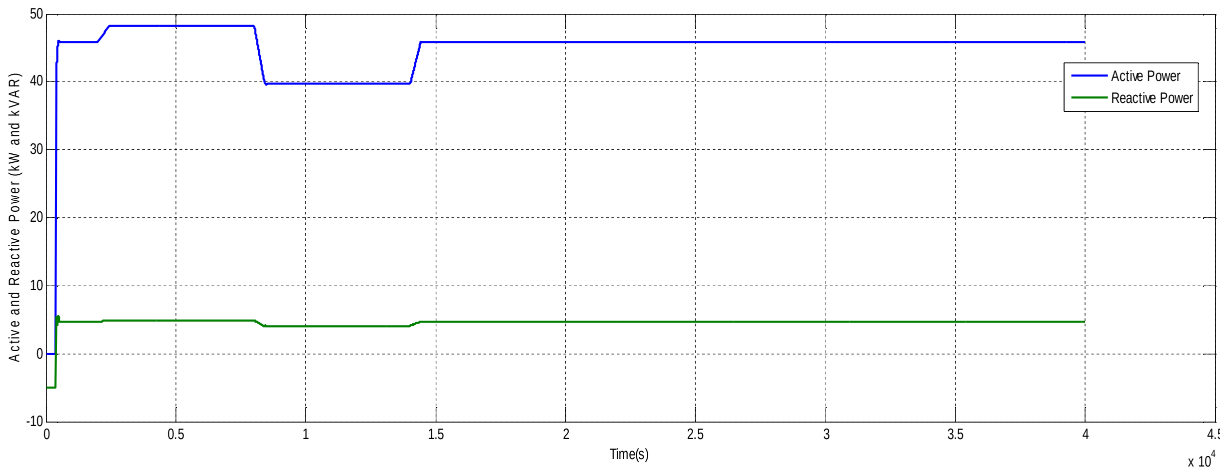


(a)Without passive shunt filter

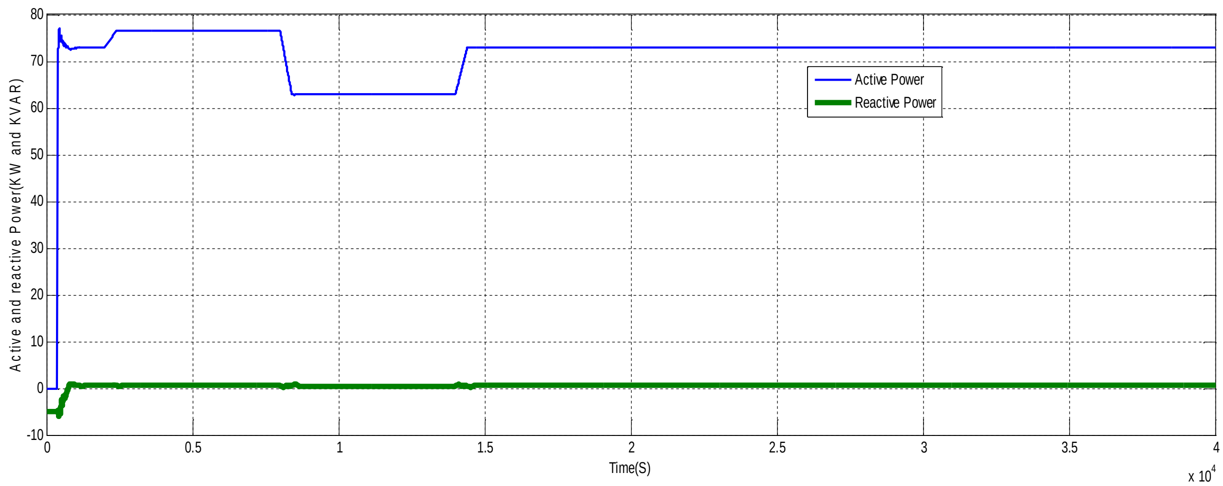


(b)With passive shunt filter

Fig.4.3 AC mains voltage and current response (a) and (b) in simulation for converter with R-L load

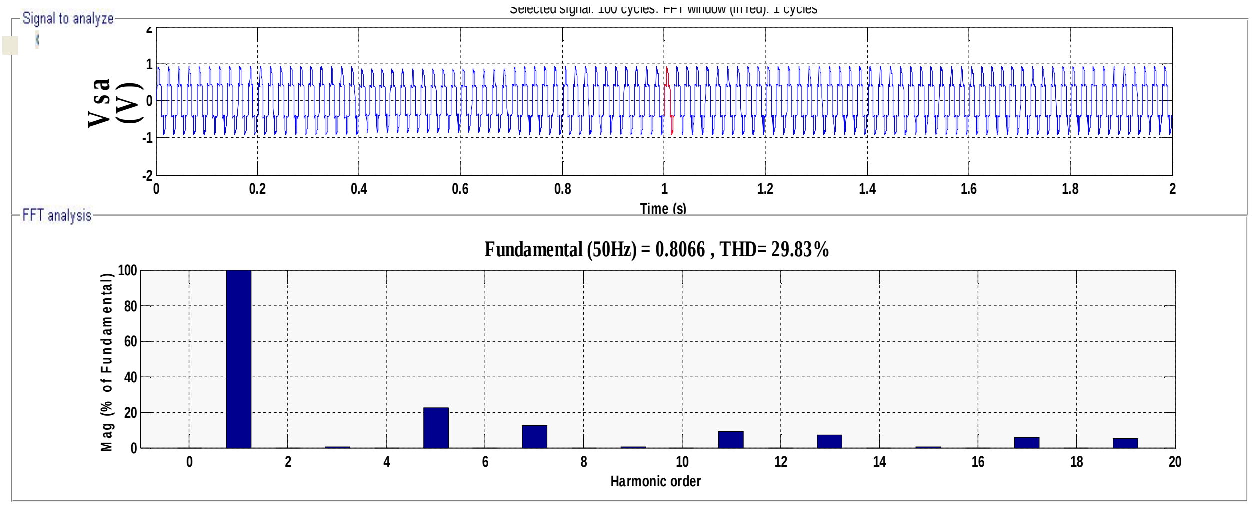


(a)Without passive shunt filter

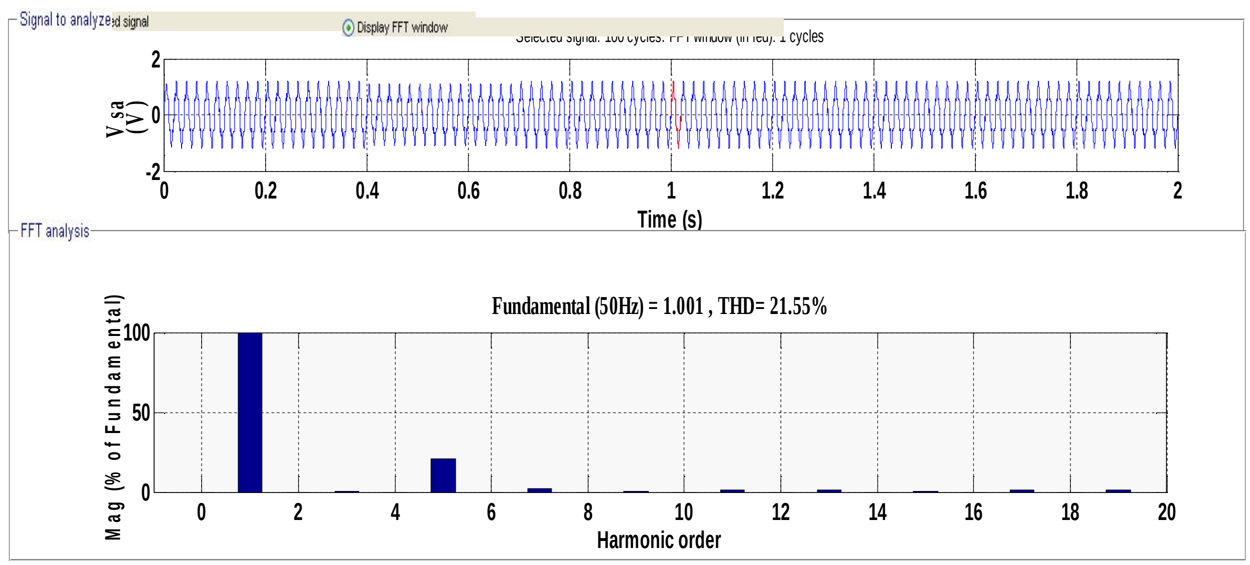


(b)With passive shunt filter

Fig.4.4 AC mains Active and Reactive power response (a) and (b) simulation for converter with R-L load

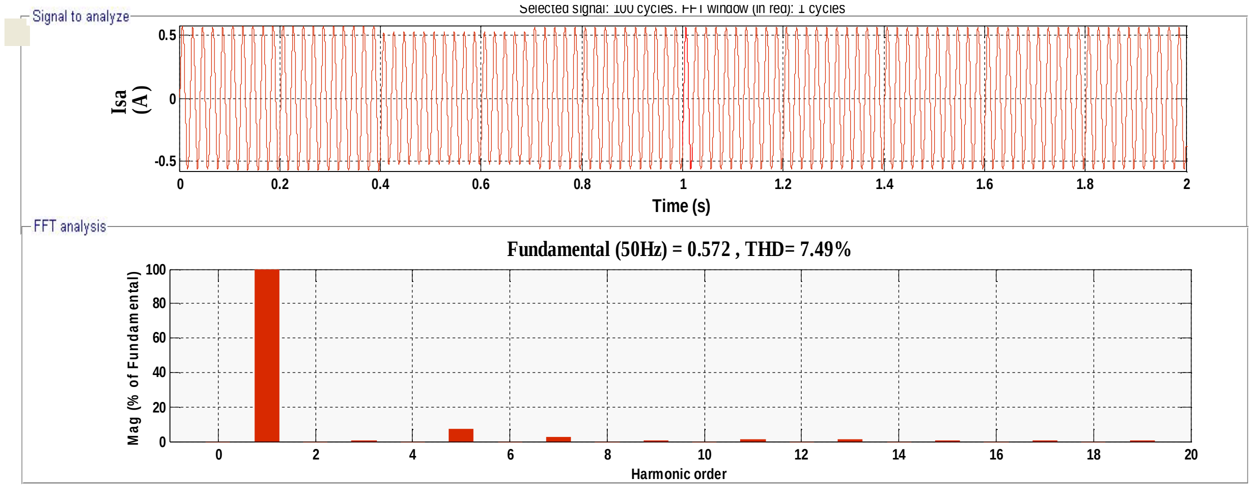


(a)Without passive shunt filter

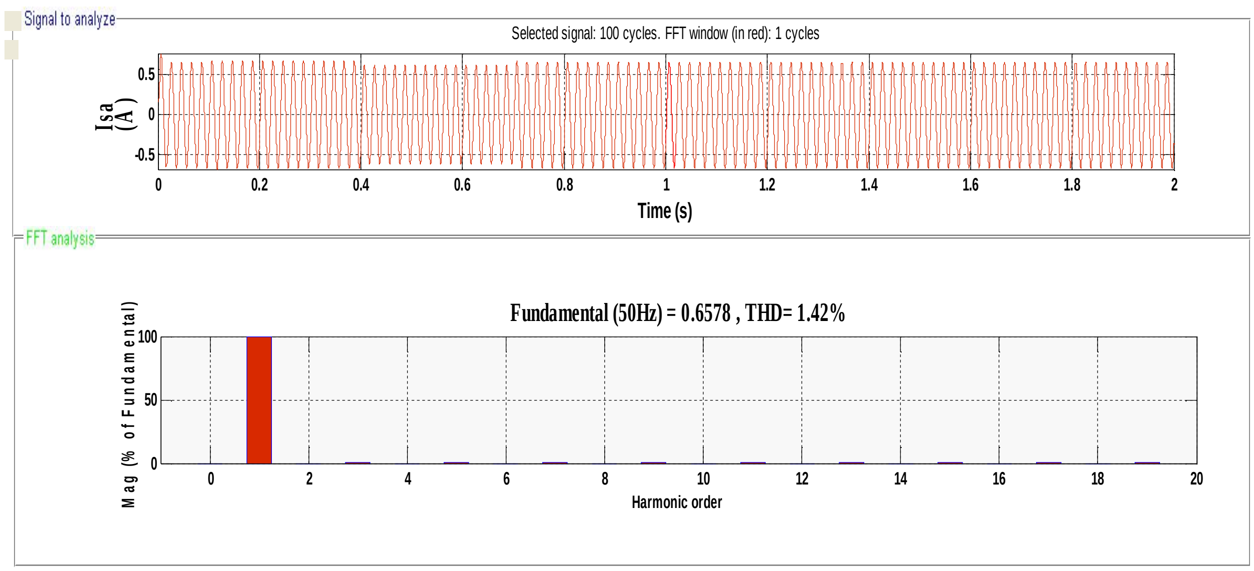


(b) with passive shunt filter

Fig.4.5 AC mains voltage response with %THD (a) and (b) in simulation for converter with R-L load



(a)Without passive shunt filter



(b) With passive shunt filter

Fig.4.6 AC mains current response in simulation for converter with R-L load of (a) and (b) comparison.

4.3 MATLAB BASED MODELING OF PASSIVE FILTER WITH TCR AND TSC

To demonstrate the performance of these passive filters with TCR and TSC feeding a three-phase converter with R-L load, these are modeled in MATLAB environment along with SIMULINK and power system block set toolboxes. Different components of these converters such as low pass filter with R-L load are simulated in MATLAB/SIMULINK.

4.3.1 Passive Shunt Filter Based Converter with R-L Load

Fig.4 shows the MATLAB model of a passive series filter based six pulse ac-dc converters with R-L load. Depending on the harmonic spectrum of the supply current, the passive filters designed are low pass filter tuned for 5th order harmonic frequency. The subsystem named shunt filter consists of 5th harmonic frequency. Based on the design carried out the filter component values are L=16mH, C=25μF, R=0.83Ω.

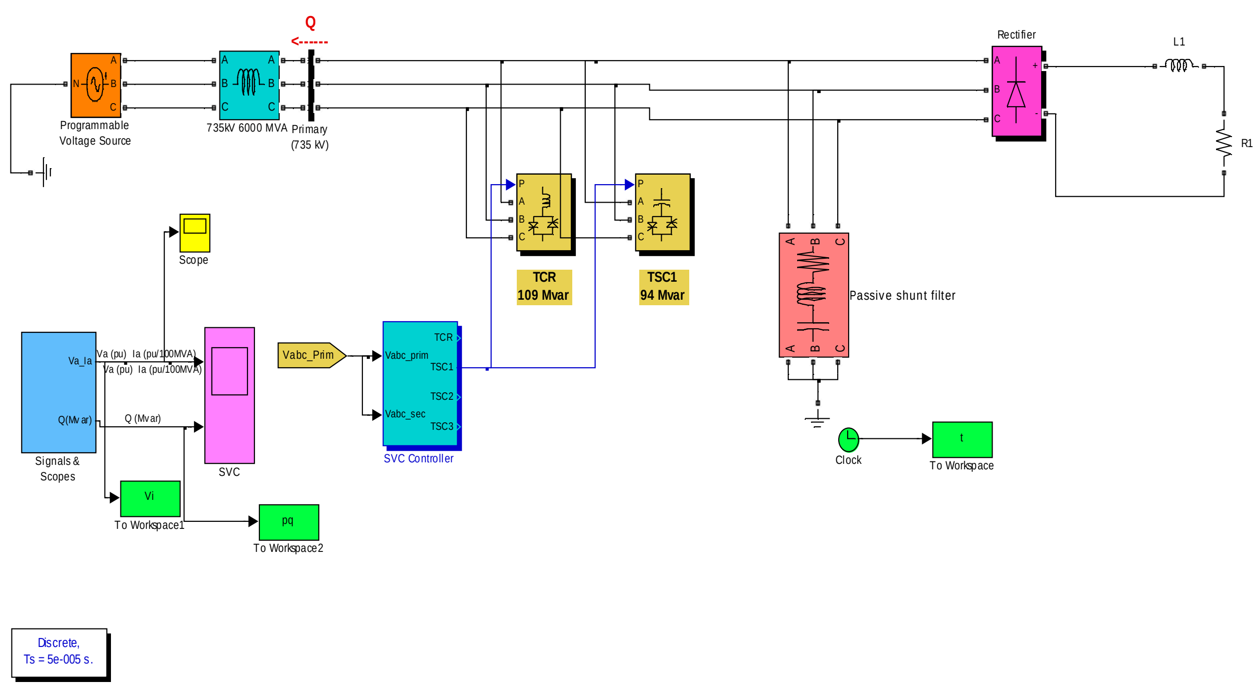


Fig.4.7 MATLAB based model of a six pulse ac-dc converter R-L load passive filter with TCR and TSC combination.

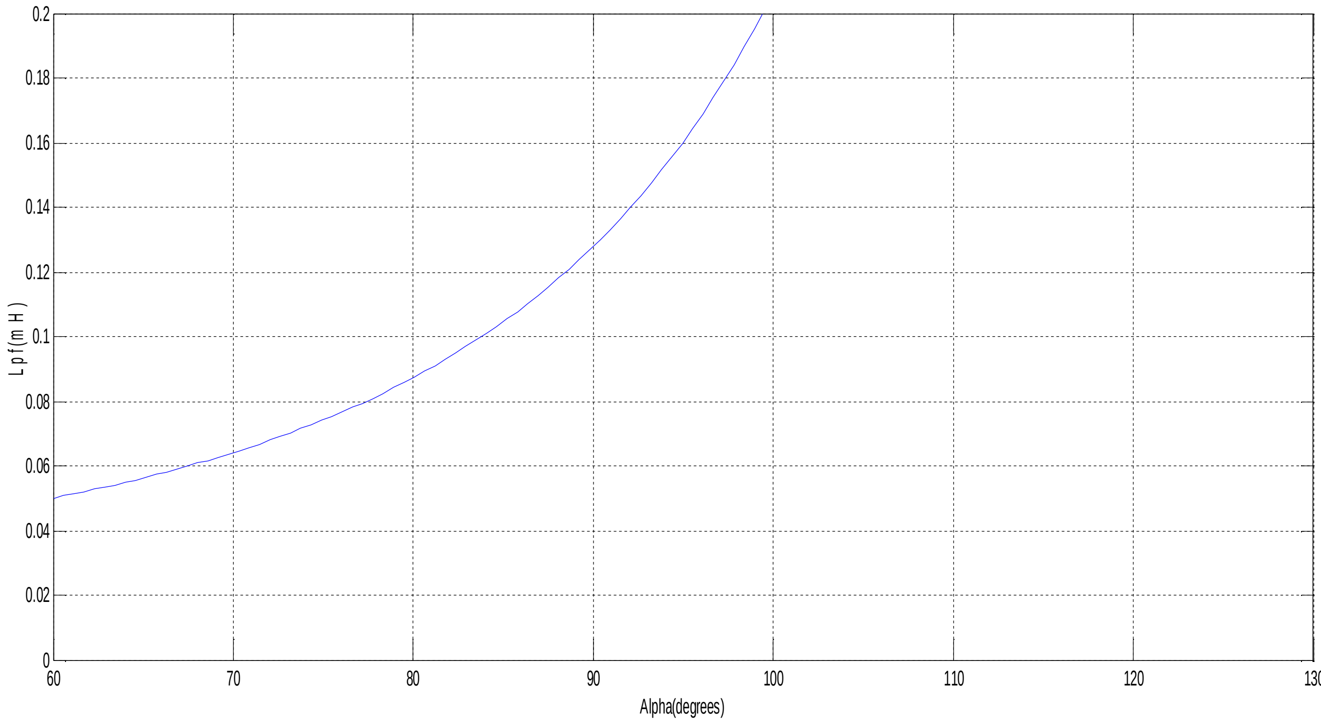


Fig.4.8 Inductance and alpha response in star delta connections

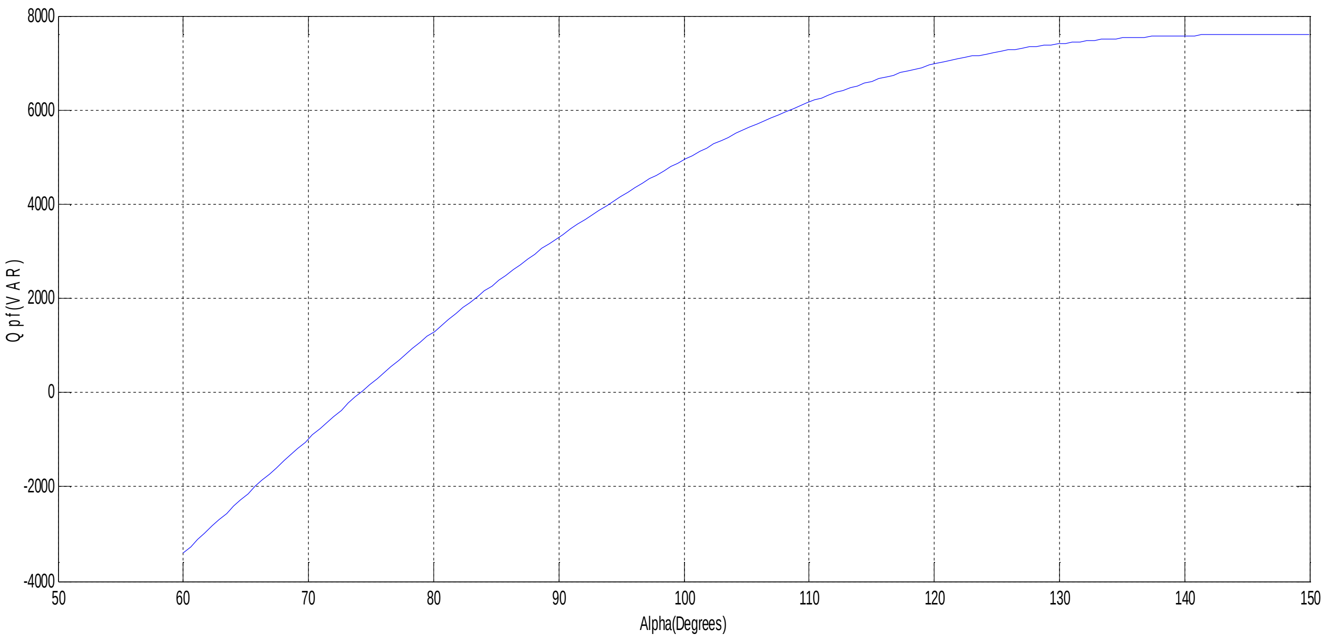


Fig.4.9 Reactive Power and alpha response

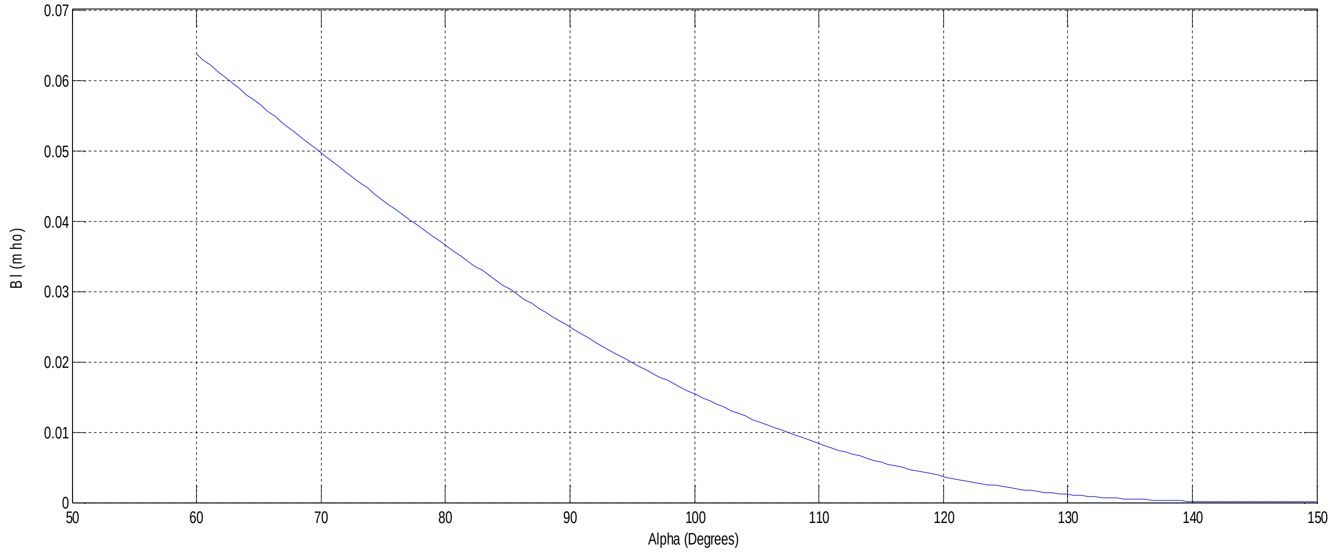


Fig.4.10 Susceptance and alpha response

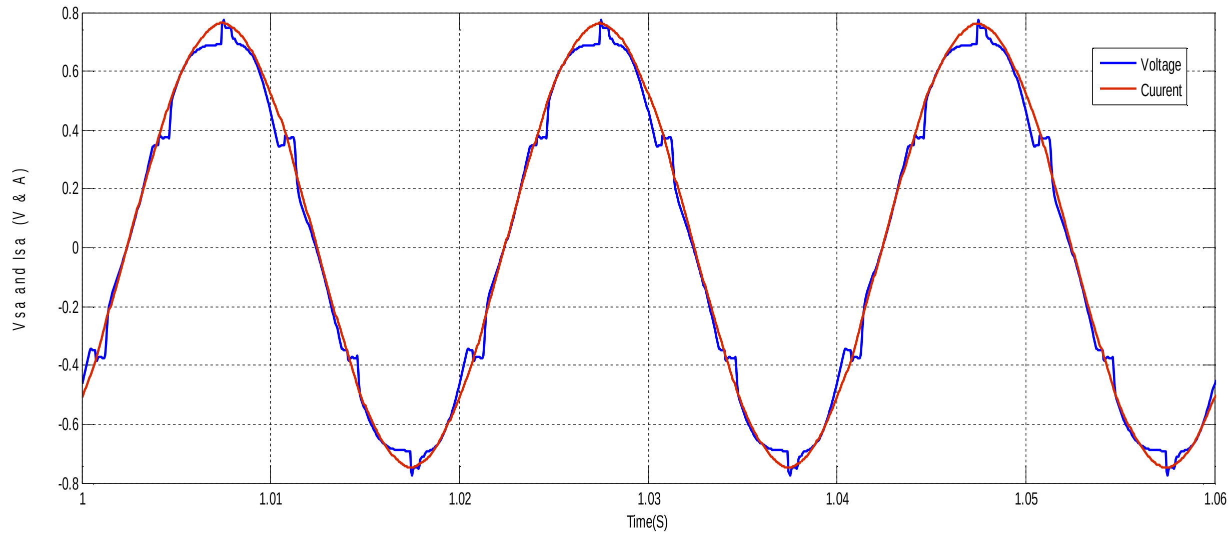


Fig.4.11. Voltage and current response of the ac-dc converter with passive filter, TCR and TSC combination.

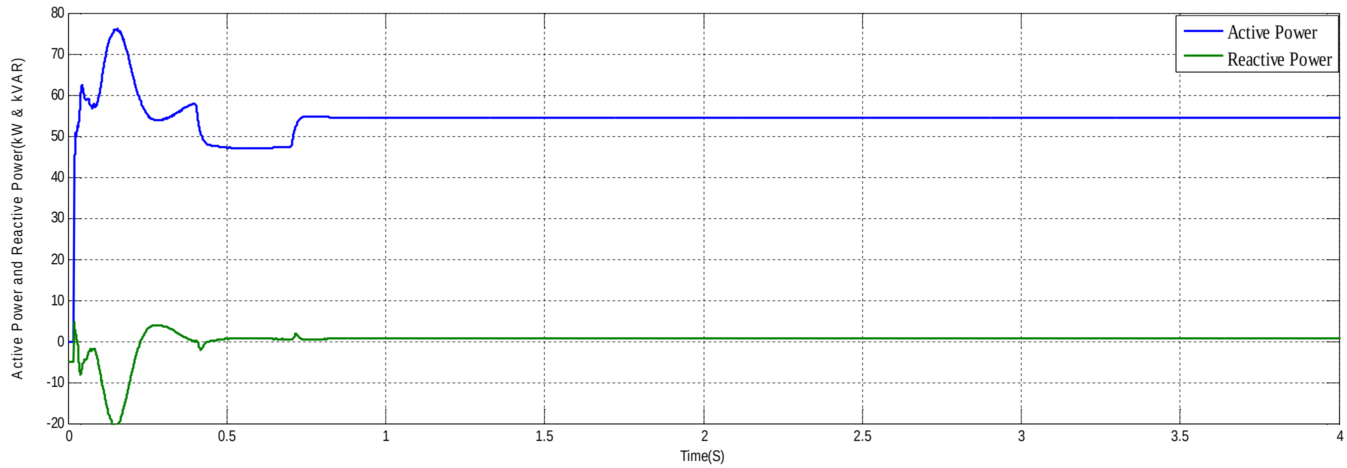


Fig.4.12 Active and Reactive power response of the ac-dc converter with the combination of passive filter, TCR and TSC.

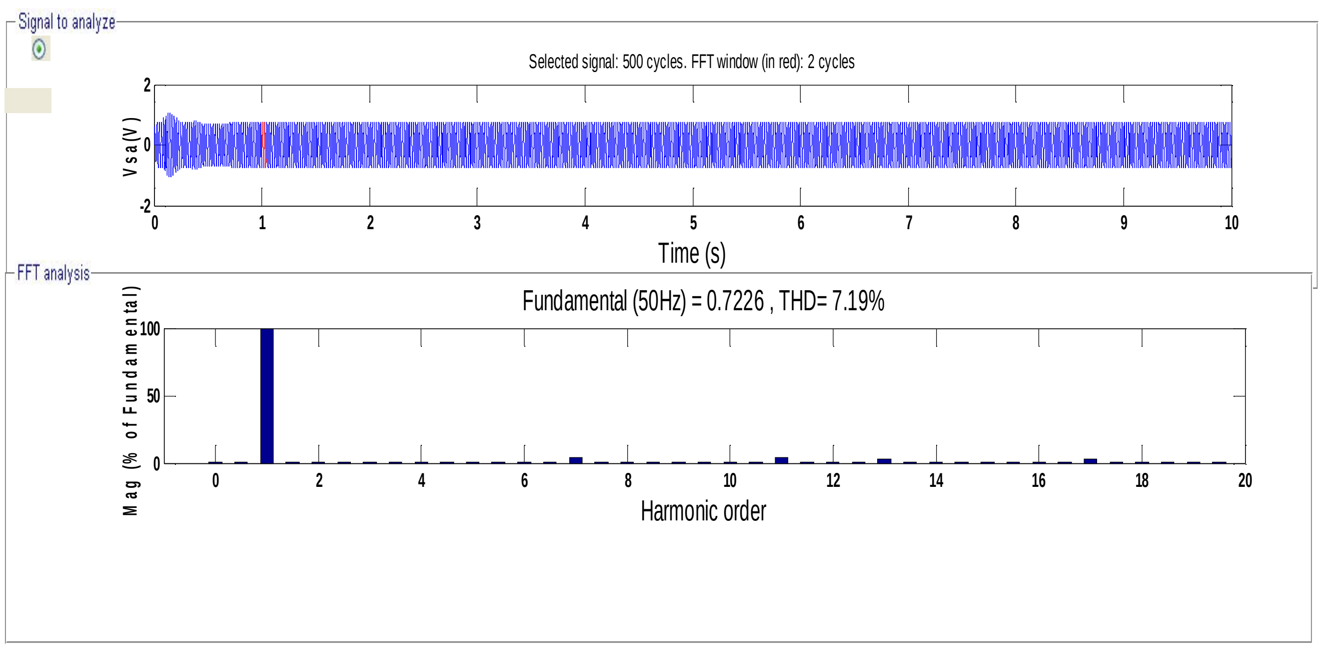


Fig.4.13. Voltage response and THD of the ac-dc converter with passive filter, TCR and TSC combination.

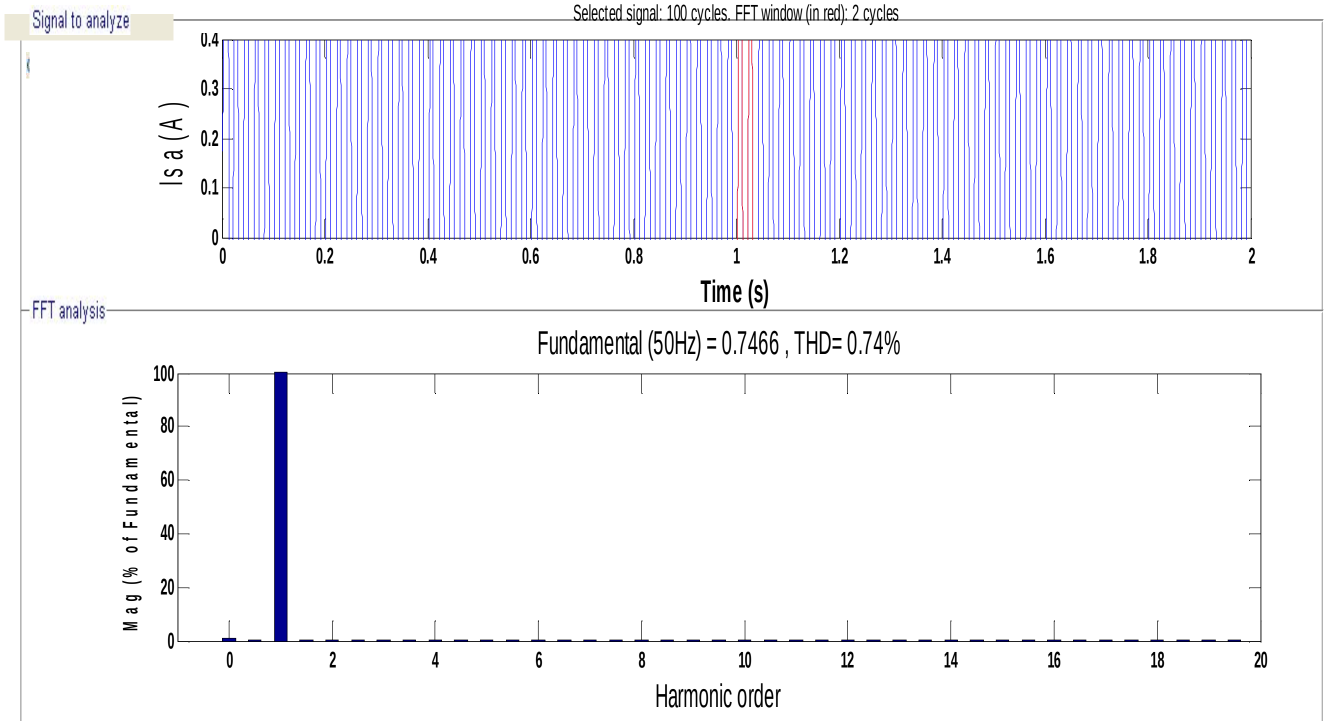


Fig.4.13. Current response and THD of the ac-dc converter with passive filter, TCR and TSC combination.

TABLE 4.2 Comparisons THD with Different Schemes

MATLAB SIMULINK MODEL	VOLTAGE THD%	CURRENT THD%	Q KVAR
WITHOUT FILTER	29.83	7.49	5
WITH FILTER	21.55	1.42	0
FILTER AND TCR-TSC	7.19	0.7466	0

4.4 SUMMARY

It has been shown that the use of TCR-TSC combination helps in reducing the passive filter capacitor rating by almost 75%. The performance of the proposed system has been verified by simulation results. The major goals were to compensate the load reactive power and current harmonics generated by the current source types of non linear load. The THD under the current source type of non linear load has been reduced for delta connection from 26% to 1.2%.

CONCLUSIONS AND FUTURE SCOPE OF THE WORK

5.1 GENERAL

The main objective of this investigation has been to evolve different power quality improvement techniques for improving various power quality indices at ac mains as well as on dc bus in ac-dc converter with R-L load. It has also intended to determine the extent of improvement in different power quality indices in various techniques for application. This research work has been on developing configurations suitable for retrofit applications, where presently a six pulse diode bridge rectifier is being used. The obtained results of various circuit configurations of front end ac-dc converters in preceding chapters have demonstrated successfully fulfilling these objectives.

5.2 CONCLUSION

- The effect of multiple harmonic sources can be investigated by applying the superposition principle.
- The SVC harmonic generation modeled by positive-, negative-, and zero-sequence harmonic sources.
- The system represented by linear models at each harmonic frequency.
- The precise evaluation of harmonic distortion must have accurate load modeling.
- Hence the TCR-TSC combination is better in SVC.

5.3 FUTURE SCOPE OF THE WORK

- This configuration can be tested in hardware.
- Multi-pulse rectifier can be added to the load as 12 pulse or 32 pulse ac-dc rectifier with R-L load.
- Induction motor can also be the load instead of R-L load.
- Active filter can be introduced to it for better performances.

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